TOWARDS INTEGRATED DESIGN STRATEGIES FOR IMPLEMENTING BIPV SYSTEMS INTO URBAN RENEWAL PROCESSES: FIRST CASE STUDY IN NEUCHÂTEL (SWITZERLAND)

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Abstract

In view of the importance of urban renewal processes, building-integrated photovoltaic (BIPV) systems can potentially provide a crucial response to the challenges of the energy turnaround. Functioning both as envelope material and electricity generator, they can simultaneously reduce the use of fossil fuels and greenhouse gases (GHG) emissions while providing savings in materials and electricity costs. These are precisely the objectives of most European energy directives, from zero- to positive-energy buildings. In Switzerland for instance, one way to achieve the objectives of the “Energy strategy 2050” is to install PV systems to cover 1/3 of the annual electricity demand. However, despite continuous technological and economic progress, the significant assets of BIPV remain broadly undervalued in the current practice. Various obstacles (technology choice, small volumes, lack of information and good examples, etc.) tend to increase the costs and reduce the acceptance of BIPV solutions. The present paper is an integral part of an interdisciplinary research project. Focusing on the architectural design issues, it presents the first results of a representative case study carried out in the city of Neuchâtel (Switzerland). The approach involves four main phases (Fig.1): (i) archetypes identification, (ii) building detailed analysis, (iii) development of architectural renewal design scenarios, and (iv) multi-criteria assessment of each scenario (energy consumption, electricity production, cost-effectiveness, and Life-Cycle Analysis). The application of the proposed approach on a case study allows us to initiate the first step towards a holistic and reliable multi-criteria comparison methodology for BIPV-adapted solutions in urban renewal design processes in the Swiss context.

Keywords:
Building-integrated photovoltaics; energy efficiency; renewable energy; sustainable architectural design; urban renewal; renovation strategy; multi-criteria assessment

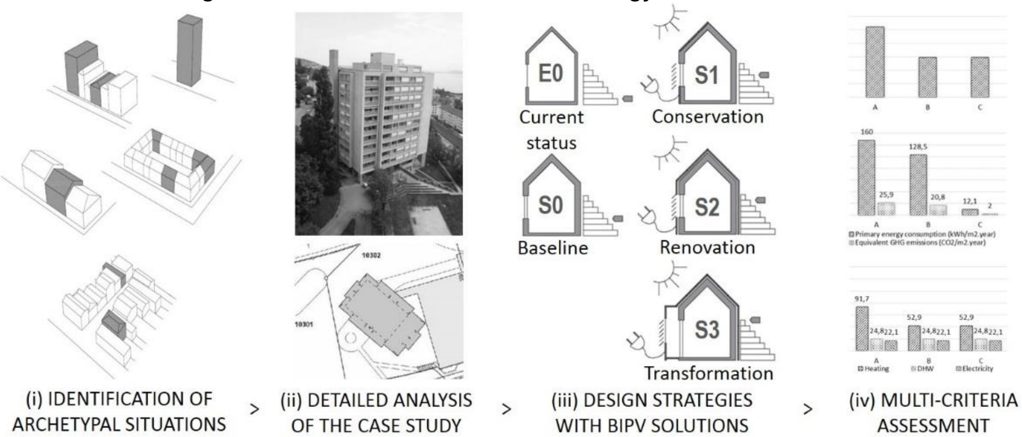

Fig. 1: Diagram of the proposed research methodology.

1 INTRODUCTION

One of the top priorities of European countries is to reduce energy consumption and the GHG emissions in the built environment. Towards this aim, since the city of tomorrow is largely already built, many strategies stress the importance of urban renewal processes towards more sustainability in terms of economic, social and environmental impacts. Indeed, there are still huge potential energy savings to be made in European countries in general, and in Switzerland in particular. Most residential buildings were built before 1985 and require large amounts of energy to ensure the minimum indoor thermal comfort [1]. In response, recent research works have started considering the large existing building stock, bringing to light the considerable importance of urban renewal strategies for the sustainability of the built environment in the next decades [2].

In parallel, one of the objectives of the "Energy strategy 2050" is to increase the use of renewable energy, and according to the International Energy Agency (IEA) it is possible to cover 1/3 of the annual Swiss demand for electricity using photovoltaic (PV) panels [3]. Such systems therefore provide a crucial response to the challenges of the energy turnaround [4].

BIPV is a growing and diverse area of research. In particular, it includes research on new products development, modelling, simulation, and assessment of their integration on buildings [5].

2 RESEARCH OBJECTIVES

Despite all this technological progress, only a small part of the available local potential for BIPV is valorized in urban areas (integration into roof and façades elements). Diverse types of obstacles limit a large-scale advanced PV integration into urban renewal processes. Most barriers are related to the limited motivation of architectural designers, a restricted knowledge of the BIPV potential and an insufficiency of aesthetically-convincing exemplary buildings [6].

To address this challenge, urban and architectural design towards increased integration – and therefore increased acceptance – could potentially provide a decisive solution. Although it remains largely disconnected from solar renewable energy issues, it represents a key element towards establishing a systematic link between BIPV and the necessary renewal of the considerable existing building stock.

Therefore, instead of considering BIPV as a technical constraint for designers, we propose a new approach based on the integration of BIPV solutions as a new "raw material" for architectural renewal projects [7,8]. By prioritizing architectural quality and dialogue with the built environment, it aims at identifying which construction elements can be substituted by the most appropriate PV components. The latter will not only fulfill the same requirements as other parts of the building envelope (water and air tightness, mechanical resistance, etc.), but also generate electricity on site from a renewable energy source.

Our work fall within an ambitious research project entitled ACTIVE INTERFACES [9] which is currently being conducted in order to study in a structured and in-depth manner the technological, spatial, legal and socio-economic parameters related to the development of new adapted solutions, taking into account diverse criteria (energy consumption, electricity production, cost-effectiveness, and Life-Cycle Analysis). Crossing over the limits of current practices, this ongoing project aims at designing and assessing BIPV-adapted scenarios embodying different urban renewal strategies in the Swiss context through a multi-criteria assessment methodology.

The present paper is the first milestone on the road towards these integrated design strategies for implementing BIPV systems into urban renewal design processes. It presents the results from a first case study in Neuchâtel, based on the analysis and comparison of different architectural renewal design scenarios. The intermediary objective is to test, validate and find ways to improve the proposed methodology.

3 PROPOSED METHODOLOGY

The methodology involves four main phases (Fig.1): (i) identification of archetypes (residential buildings); (ii) analysis of the building (study of the current status and the thermal envelope's construction details); (iii) development of three architectural renewal scenarios embodying different levels of intervention; (iv) multi-criteria assessment of each design scenario.

3.1 Identification of archetypes

We are focusing on Neuchâtel considering that it is representative of the typical middle-size city of the Swiss Plateau. Based on an urban analysis of its building stock, five residential archetypes were identified. The purpose is to select a representative building for each archetype to carry out a series of real case studies. These five archetypes were defined based on the following selection criteria (Fig.2), which are related to the opportunity to implement BIPV elements: i) construction period, ii) urban context (adjacent or isolated building), iii) solar access potential on roof (sloped or flat), iv) and façade (floors), v) heritage level of protection (protected, common or unattractive).

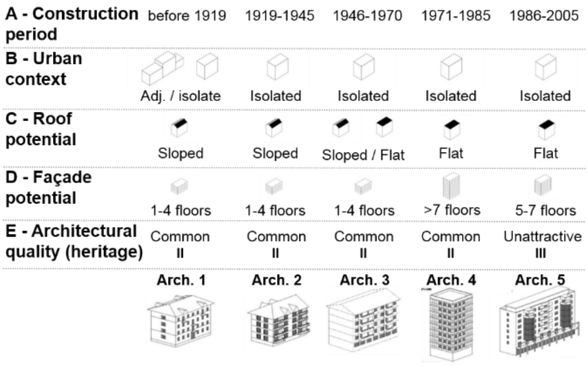

Fig. 2: Definition of five archetypes.

3.2 Detailed analysis of the case study

The building presented in this paper corresponds to the archetype 4 (Fig. 2). It is a typical residential building of the 70's, constructed at the beginning of the oil crisis (1972-1976) (Fig.3). Consequently, thermal considerations have had a rather small influence on the design of the envelope. It presents eleven-stories, consisting of 52 apartments and 5,263 m^2 of living floor area [10].

Fig. 3: Building image (current status).

A study of the construction details is crucial to detect all BIPV integration opportunities in the building envelope (roof and facades). In this case, façades are made with concrete prefabricated elements consisting of: 12cm of reinforced concrete, 4cm of expanded polystyrene (EPS) insulation, and an exterior facing concrete of varying thickness coated with a crushed stone agglomerate. Openings present double glazing and wood-metal frame. The flat roof is composed by 22cm of reinforced concrete, 6cm of EPS insulation, and 5cm of gravel. In terms of active systems, the building is connected to a central heating covering heating and domestic hot water (DHW) needs.

3.3 Design renewal scenarios description

Following the methodology (Fig.1), we defined five renewal scenarios from an architectural point of view. We started with the analysis of the **E0-Current status** scenario, which provides all the information about the building and reflects its actual situation. The **S0-Baseline** scenario -without BIPV strategies- aims at achieving at least the current legal requirements defined by SIA 380/1 [11], in accordance with current practices. The last three design scenarios incorporate BIPV strategies and are defined as follows. **S1-Conservation**: aims to maintain the expression of the building while improving its energy performance (at least current legal requirements). **S2-Renovation**: has as purpose to maintain the general expressive lines of the building while reaching high energy performance (at least *Minergie* standard); **S3-Transformation**: best energy performance and maximum electricity production possible with aesthetic and formal coherence over the whole building (at least “2000WattsSociety” targets [12]).

3.4 Renovation strategies for each scenario

Following the architectural criteria defined in section 3.3, for **S0**, we propose to add an internal insulation and substitute the existing windows. For **S1**, in addition to the interventions of S0, we propose to cover the roof (250m^2) and the railing of the windows (431m^2) using BIPV elements, respecting the building's expression. For **S2**, we propose an external insulation façade system including the replacement of existing windows, and placing BIPV elements in the entire roof, the railing of windows and window surroundings (254m^2), while maintaining the main lines of the building's expression. Finally, for **S3**, we propose a prefabricated façade element to plug-in directly on the existing façade, including insulation (ventilated facade), new windows and BIPV elements covering all opaque surfaces (514m^2). The detailed visualization of the different scenarios for this first case study are detailed in [13].

3.5 Definition of assessment indicators

To carry out a multi-criteria evaluation of the design scenarios, four groups of indicators are defined. They assess and compare the scenarios' performances in terms of energy, economic and environmental aspects (Table.1). This preliminary definition will provide the basis for the more in-depth assessment in the future steps of the research project.

1-Energy consumption	
- Primary energy consumption	*kWh/m².y*
- Equivalent GHG emissions	*$kgCO_2/m^2.y$*
2-Photovoltaic installation	
- Electricity production	*MWh/year*
- Self-consumption potential	*%*
3-Cost-effectiveness	
- Annual rent increase	*%*
- Accumulated global cost	*CHF*
4-LCA - Life Cycle Analysis	
- Embodied energy balance	*$MJ/ m^2.y$*
- Global Warming Potential	*$kgCO_2/ m^2.y$*

Table. 1: Assessment indicators.

4 SIMULATION

The tool used to estimate the assessment criteria related to energy consumption, emissions and photovoltaic production is *DesignBuilder*, based on the *EnergyPlus* simulation engine [14]. For the cost estimation we used the EPIQR tool [15], developed for testing different renewal scenarios and identifying the best performing one(s).

4.1 Input data for energy consumption

The U-values for the current status -scenario E0- are defined through a detailed analysis of the exiting envelope [16]. For scenarios S0 and S1, U-values target corresponds to SIA 380/1 requirements, and for scenarios S2 and S3 they are the result of the construction detail proposition (Table.2).

Scenario	E0	S0	S1	S2	S3
Façade	0.9	0.2	0.2	0.1	0.1
Roof	1.3	0.2	0.2	0.2	0.2
Glazing	2.6	1.3	1.3	1.1	0.8
Vent. r/h	2.0	2.0	1.0	0.5	0.5

Table. 2: U-value (W/m^2K) and ventilation ratio.

4.2 Input data for photovoltaic installation

The choice of the BIPV components to be used in scenarios S1, S2 and S3 responds to the will of carrying out a rehabilitation which preserves the architectural quality of the building, while compromising as little as possible the level of electricity produced. We have chosen standard panels for the roof [17] and BIPV customized elements with frameless panels for the façade [18]. Based on the monocrystalline (sc-Si) technology of cells, an efficiency of 14% is estimated [19]. The cost is estimated between 245 and 445 CHF/m², including inverters, wiring and accessories [20].

4.3 Input data for global cost-effectiveness

One of the main concerns about BIPV installations is related to the economic and financial aspects. Therefore, the precise evaluation of the costs is an essential aspect of the proposed methodology. The estimation of the accumulated cost due to energy consumption is calculated obtaining the cost-effectiveness for each scenario, using energy cost savings and extra revenues from the sale of PV electricity produced (Fig.7). This method is recommended by the cost-optimal methodology applied to renewal processes [21], considering medium- or long-term investment scenarios. For this case, we have considered a horizon of 50 years (lifespan), 3% of interest rate and 1% increasing energy price per year [1].

5 RESULTS

5.1 Energy consumption

The heating need target set by the SIA 380/1 for housing, considering an envelope area (A_{th}) of 3,922 m² and a floor area (A_E) of 5,263m² is 38 kWh/m²·year. The target is achieved for the four scenarios, corresponding to a 53% saving on the heating demand. In terms of non-renewable primary energy consumption, scenarios achieve, with respect to E0; -31%(S0), -61%(S1), -78%(S2) and -89%(S3) (Fig.4). To convert the results from final to primary energy and CO_2 equivalent emissions, we have used coefficients from SIA 380/1 [12]. For electricity: 2.970 kWh_{PE}/kWh_{FE} and 0.154 $kgCO_{2eq}/kWh_{FP}$ electricity); for oil heating 1.690 kWh_{PE}/kWh_{FE} and 0.403 $kgCO_{2eq}/kWh_{FP}$.

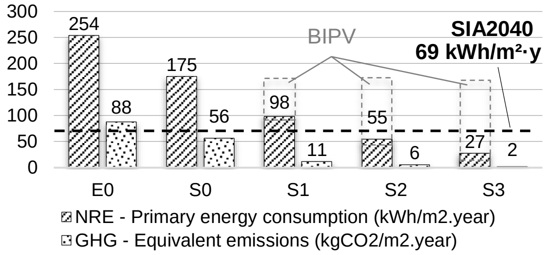

Fig. 4 Net energy consumption and emissions.

The values obtained for the current situation far exceed the Swiss target value set by SIA2040 based on the "2000WattsSociety" [13], which in this case sets the limit of consumption to 69 kWh/m² per year (for electricity, heating and DHW) (Fig.4). These results show the changes needed to achieve the goals set by the "EnergyStrategy2050" and highlight the importance of strategies to promote urban renewal processes. To achieve this targets, it is crucial to propose mixed strategies composed by passive and active measures to take into account the origin of each energy source. For this reason, we have proposed, in addition to the envelope renovation, a modification of HVAC systems for the scenarios S1, S2 and S3, replacing the existing oil boiler by an air-water heat-pump to increase the self-consumption potential and reduce energy consumption of heating and DHW.

5.2 Photovoltaic installation

Concerning the BIPV strategy implemented in scenarios S1, S2 and S3, the estimated production of the installation is 75 (S1), 128 (S2) and 174 (S3) MWh/year. In terms of electricity annual coverage ratio, it represents 16% (S1), 33% (S2) and 48% (S3) of the domestic electricity consumption, taking into account the implementation of a new heat-pump to cover all heating needs. The results have been obtained through hourly simulations during a representative year (Fig.5).

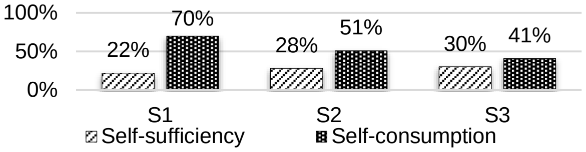

Fig. 5: Self-consumption potential.

5.3 Global cost-effectiveness

The global costs of renewal scenarios correspond to 1,004,400 (S0), 1,403,992 (S1), 1,995,252 (S2) and 2,763,750 (S3) CHF. The difference lies in the different passive strategies and the BIPV elements. We have estimated the repercussion of the renovation cost on the price of annual rent, as compared with the average value of the rent in the region of Neuchâtel, estimated at 220 CHF/m²·year [1]. In this case three different thresholds are analyzed: 3% for minimum profitability, 4.5% for average profitability and 6% for significant profitability (Fig.6).

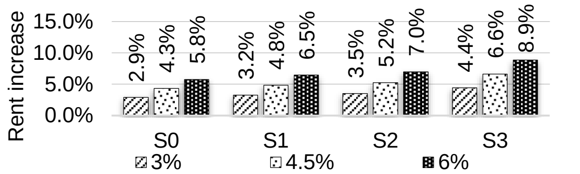

Fig. 6: Annual rent increase.

To estimate the global cost-effectiveness, we used energy savings and electricity production (including 0.8% of decreasing production per year according to the guaranteed performance of PV elements [17]), taking into account the sale and purchase price of electricity 0.2 CHF/kWh and 0.1 CHF/kWh for heating oil, tax included.

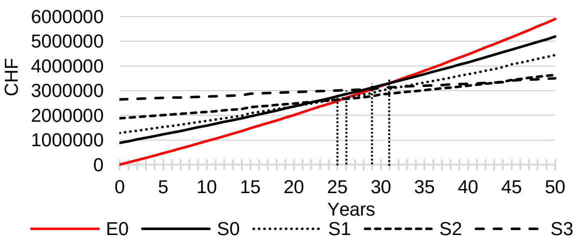

Fig. 7: Accumulated cost.

Through the accumulated cost due to energy consumption (Fig.7) we represent graphically the performance of each scenario. Financial aid to tackle the investment corresponds to 30% of the PV installation cost [22]. Using these data, and taking into account maintenance and repair-replacements costs [23] for the BIPV installation, the payback time of each scenario has been calculated using the DCF (discounted cash-flow) methodology by net present value (NPV), leading to 31 (S0), 26 (S1), 25 (S2) and 29 (S3) years, taking into account the real self-consumption with no-battery systems (electricity production consumed on-site by the building). The BIPV strategy thus presents a shorter payback time thanks to the extra revenue generated by the produced electricity.

5.4 Life-Cycle Assessment (LCA)

The results of the Life-Cycle Assessment of each renovation scenario shows that scenarios S2 and S3 respect the Swiss targets, both in terms of embodied energy (Fig.8) and GHG emission (Fig.9) thanks to the change in the type of energy source and the low-emissions renovation materials proposed (for S2 and S3). Calculations have been done with the ECO-BAT application taking into account a service life of 30 years (PV), 20 years (HVAC systems) and 40 years (construction materials) [24].

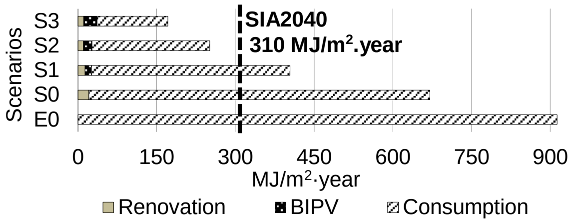

Fig. 8: Embodied energy balance (MJ/m²·y).

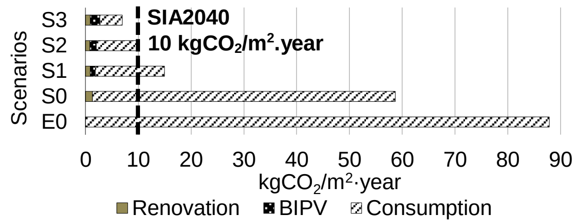

Fig. 9: Global Warming Potential (kgCO₂/m²·y).

6 CONCLUSION

Based on the results of the evaluation, it seems clear that energy renovation projects without the integration of renewal energy in general and BIPV in particular are no longer an option if we want to achieve the objectives of the "Energy strategy 2050". Today, renovation projects improving the building envelope with a very high level of thermal energy performance are necessary, but not sufficient. Compensating buildings' energy consumption by producing electricity on site has become the number one priority. In this sense, by proposing new adapted BIPV solutions for urban renewal processes, the research contributes to advancing architectural and construction design practices in this direction. At an early stage of the research, the results of this preliminary application case study highlight several interesting elements, such as the best cost-effectiveness of the BIPV scenario. By taking into account a simple passive strategy, 31% (interior insulation) and 61% (exterior insulation) savings of heating are achieved. As we can see in this first case study, we can achieve more than 89% of total savings by introducing mixed strategies (passive, active and renewable energy systems) (Fig.4). Economic aspects, in particular, appear as key elements to understand obstacles and find ways for getting around them. As such, the type of financing is an essential issue and will require specific attention in the future development of the project.

This study also allows a first validation of the proposed methodology and opens up new perspectives for the upcoming process of finalization and refinement. Finally, after these various refinements will have been carried out, further phases of the research will consist in applying the methodology to other archetypal buildings. These upcoming case studies will ensure the validation of the finalized methodology and enable the extrapolation of the most performing BIPV renovation strategies at the urban scale. Moreover, these case studies will provide architects, installers and public authorities with a catalogue of innovative and adapted “best practice” solutions for a large-scale advanced BIPV integration into urban renewal processes.

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8 REFERENCES

1. Office fédéral de la statistique. (2015). Neuchâtel.

2. Riera Pérez M., Rey E. (2013). A multi-criteria approach to compare urban renewal scenarios for an existing neighbourhood. Case study in Lausanne (Switzerland). Building and Environment, 65(2013), 58-70.

3. IEA (International energy agency). (2002). Potential for Building Integrated Photovoltaics, Report PVPS T7-4. Switzerland.

4. SFOE. (2014) Energy Strategy 2050. Zurich.

5. Frontini, F. et al. (2012). A case study of solar technologies adoption: criteria for BIPV integration in sensitive built environment. Energy Procedia, 30(2000), 1006-1015.

6. Heinstein P., Ballif C., Perret-Aebi L.E. (2013). Building Integrated Photovoltaics (BIPV): Review, Potentials, Barriers and Myths. Green, 3(2), 125-156.

7. Aiulfi D., Rey E. (2010). Les technologies vertes, matières premières pour la créativité des architectes. Neuchâtel: MICRO 10, specialized lectures.

8. Rey E. (2014) From Spatial Development to Detail. Collection Notatio. Lucerne: Quart Publishers

9. Rey E. et al. (2015), Building integrated photovoltaics. ACTIVE INTERFACES, NRP 70(Energy Turnaround) and NRP 71 (Managing Energy Consumption), Kick-off Meeting Luzern, 24 April

10. Bauer F., Oswald D., Trachsel C., Rey E. (2013) HOLISTIC: Retour d'expériences. Public Final Report. Neuchâtel: CONCERTO Program.

11. SIA (2009). SIA 380/1:2009 L'énergie thermique dans le bâtiment. Zurich.

12. SIA (2011). SIA 2040: La voie SIA vers l’efficacité énergétique. Zurich.

13. Aguacil S., Lufkin S., Rey E. (2016). Architectural design scenarios with building-integrated photovoltaic solutions in renovation processes: Case study in Neuchâtel (Switzerland) (Switzerland). PLEA 2016, Los Angeles, USA.

14. DesignBuilder (2015), Retrieved April 23, 2015, www.designbuilder.co.uk.

15. Flourentzou F., Droutsa K., Wittchen K.B. (2000), EPIQR software. Energy and Buildings, 31(2000), 129-136.

16. Bauart (2015). Stratégie d'intervention sur les Immeubles Troncs 12-14. Neuchâtel.

17. Meyer Burguer (2016). MegaSlate PV panels, Retrieved April 25, 2016, from http://energysystems.meyerburger.com/.

18. CSEM (2015). Selective filter technology to coloured solar modules, from www.csem.ch.

19. Cerón I., Caamaño-Martín E., Neila F.J. (2013) ‘State-of-the-art’ of building integrated photovoltaic products. Renewable Energy, 58(0)127-133.

20. Solar-toolbox. (2015). Retrieved January 10, 2016, from www.solar-toolbox.ch.

21. BPIE (2013). Implementing the cost-optimal methodology in EU Countries. Brussels.

22. Swissgrid. (2015). Retrieved April 23, 2015, from www.swissgrid.ch.

23. NREL (2003). Guidelines for the Economic Evaluation of Building Integrated Photovoltaics Power Systems. Colorado.

24. ECO-BAT (2016), Retrieved January 13, 2016, from www.eco-bat.ch