論文の内容の要旨

論文題目　　Studies on light-transmissive photovoltaics (LTPV): patterns of integration into architectural design
（ 透光性の太陽光発電モジュールについての研究：建築デザインへの展開の類型化 ）

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Within the last years many books about PV in buildings were published. On average they include 15-20 case studies. Even though opaque PV modules are contributing by far the lion's share in terms of module production, it is interesting to see that about one third of the BIPV case studies in the studied literature are using light-transmissive photovoltaic (LTPV) laminates, mostly bespoke solutions. This raises the question, whether LTPV are more appropriate for building integration than opaque PV, even though they are an absolute niche product for the manufacturers. In contrast to the importance that LTPV have as case study examples, their special features are hardly dealt with, at best in a brief section about transparency. An analysis with the main focus on LTPV, that addresses the issue of a comparative analysis of built examples based on a comprehensive corpus, is lacking.

To address LTPV separate from opaque PV is based on its translucent or semi-transparent properties and qualities. The ability to change the degree of light-transmittance, for illumination or shading, for allowing or preventing views, for letting in desired heat gains or blocking undesired heat loads, while fulfilling the basic function of PV as power generator, plus the aesthetic qualities of rich shadow plays, colour and texture, all in one building and architectural element, elevates its flexibility beyond opaque PV.

The analysis of PV in buildings has commonly been based on opaque PV due to the overwhelming market share. My thesis is, that certain issues, only recently noticeable or noticeable only when looking from the point of LTPV, are showing the limitation of this approach. This study is meant to fill the gap, the lack of research into LTPV as an architectural element.

A corpus of ~600 realised LTPV projects from the last two decades was compiled. This means about four to five times more built examples than the case studies published in the reference literature about PV in buildings. From this full corpus 116 projects were selected for a comparative analysis, to establish and verify key design parameters for LTPV.

A Six-Level-Matrix is suggested as a framework for the analysis of built examples. Architectural integration has to be considered on all six levels. Analyses so far have focused mainly on the two elemental levels 'solar cell' (level 1) and 'solar panel' (level 3), and the first

integrational level 'built form' (level 5). However, as solar cells are not available in any shape, the problem of how to manage the distribution of solar cells in an arbitrarily shaped solar panel arises. This controversy gave rise to the consideration of the 'cell-group form' (level 2) and similarily of the 'panel-group form' (level 4) as mediating compositional and intermediate levels. An analysis of the two newly considered intermediate levels, and a subsequent categorisation of built examples was done in this study for the first time. An extension of the analysis beyond the building envelope into the macro-scale environment is suggested and included in the Six-Level-Matrix as the final level 'urban / landscape form' (level 6), to include non-building projects, integrated urban surfaces and new forms of energy generating, performative landscape patterns.

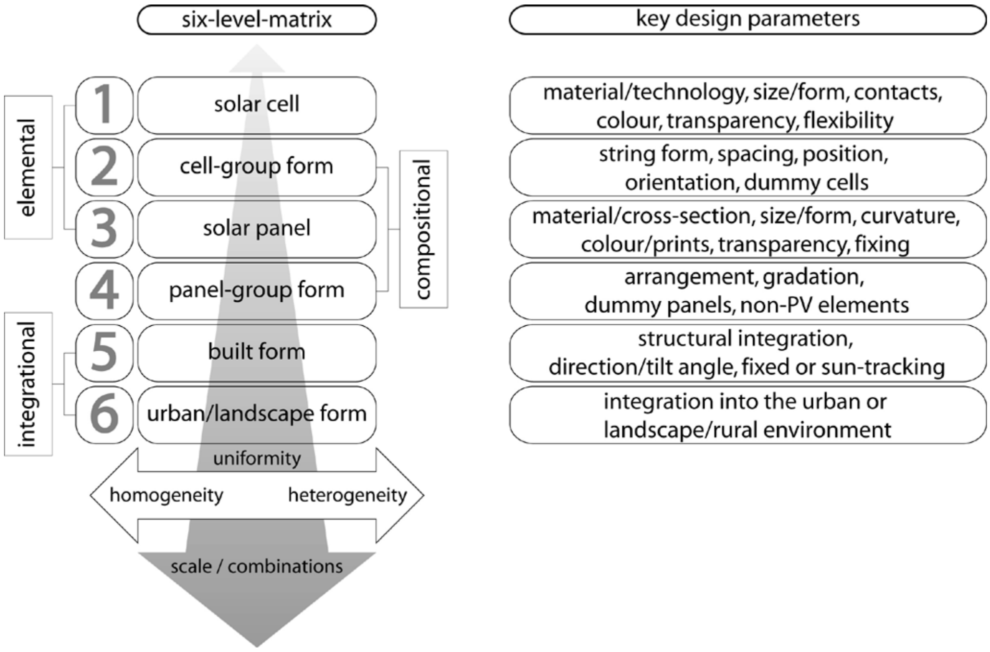

Fig.1: Six-Level-Matrix and key design parameters
with the two axial tendencies for scale / combination and uniformity (homogeneity / heterogeneity)

Regardless the technology a large variety of different designs are achievable. It became clear, that the two major technologies crystalline silicon PV and thin-film PV provide different opportunities, for influencing the level of transparency, for daylighting, and for the provision of visible connection between inside and outside. Whereas light-transmissive thin-film PV is a rather unobtrusive architectural material very similar to tinted glass, light-transmissive crystalline silicon PV has a strong visual impact and requires much more attention during the design and planning stage. However, severe restrictions may yield surprising opportunities. The analysis has shown, that the manufacturer independent standardisation of crystalline silicon cells provides architects and engineers in collaboration with PV companies the tools for experimentation and innovation. The result is an astonishing flexibility in influencing the key design parameters. The suggested Six-Level-Matrix has not only helped in understanding the integration process of PV into buildings, but has also opened the door for a more analytic approach in generating alternative patterns for LTPV, as was exemplified with two design proposals for alternative PV patterns.

It appears reasonable to state, that the full range of available PV materials has not been equally applied to LTPV. It is not only the active PV technology itself, that an architectural LTPV element is made of. Already the required encapsulation provides opportunities for variations. Especially here, the combination of at least two uniquely different materials, photovoltaic semiconductor and encapsulant, with their inherently different material characteristics and visual appearance could offer an extended range of combinatorial and customisable choice still waiting to be fully exploited. Furthermore, the combination with other non-PV elements provides more opportunities and is independent of the used PV technology. In fact, such additions can bridge between the different technologies, between PV technology and architecture, and finally between PV technology and widespread social and cultural acceptance.