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Process-related risks in refurbishment of dwellings using prefabricated wall elements with integrated PV and ventilation ducts

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Abstract. Prefabricated façade elements with integrated technical infrastructure is an attractive technology for refurbishment of existing dwellings. Heating and cooling demand can be reduced, local energy production introduced, and indoor air quality be improved, with disturbance to the tenants and building site being small and of short duration compared to more traditional building processes. On the other hand, unexpected events could largely reduce these benefits. Thus, risk management of the building process is of great importance. Focus group interviews and workshops were arranged before and after the building phase in a pilot project using such elements in Oslo, Norway. Representatives of building owner, design team and contractor contributed actively at the workshop. In a pre-building phase workshop, a range of hazards were identified and prioritized using a participative process facilitated by a neutral moderator. A large proportion of the prioritized risks in the building phase were connected to the renovated flats being occupied during the renovation. Other significant identified risks related to transport and logistics, and undetected challenges in the existing construction. Mitigation included prioritizing tenant information, including direct dialog, and increasing the presence of on-site workforce both for coordination with tenants and in order to respond quickly to unforeseen events. The participants emphasized that an open, cooperative processes with a high degree of trust and sense of a common goal had been important for the robust design that was developed prior to the workshop. During the retrospective evaluation, the participants concluded that the risk mitigation procedures had been successful in preventing some events as well as reducing the consequences of others. However, some of the measures to mitigate an identified risk of rain intrusion were inadequate, and it was acknowledged that the combination of bad weather and long working days could have identified this as preventable.

1. Introduction

In order to reduce emission of gases with global warming potential, reducing the energy demand of existing buildings is identified as an important goal. The European Union is committed[1] to increase energy efficiency of the building stock through increasing the rate of building renovation improving energy performance and indoor climate.

The project "Robust and Reliable technology concepts and business models for triggering deep Renovation of Residential buildings in EU" (4RinEU) has the overall objective of defining robust, cost-effective, tailorable, deep renovation technologies and usable methodologies, feeding into reliable

[1] Directive (EU) 2018/844

business models. The project was established on the premise that uncertainties in terms of costs and benefits in the life cycle is a barrier against deep renovation, and that more cost efficient and time saving renovation concepts can help overcoming these. Prefabricated façade elements including technical installations, including a Renewable Energy Source (RES), is one of the defined renovation technologies within 4RinEU.

It is postulated that this renovation technology can reduce heating and cooling demand, improve indoor climate and add local renewable energy production through a cost-efficient process with little negative impact on the building users and the environment, as it is possible to do the construction work without relocating inhabitants and with little need for rig area. On the other hand, the consequences of some undesirable events could be greater than in a traditional building process, exactly because the buildings are in use during the construction work.

Within the framework of the 4RinEU, a deep renovation demo project was developed together with Boligbygg Oslo KF – a municipal enterprise that owns, manages and lets social housing in Oslo. Before the deep renovation process, prefabricated elements with integrated technical components were not established on the market, a fact which added to the perceived project risks. For this Norwegian demo, integration of PV panels and ventilation ducts were chosen to be integrated in the elements.

1.1. Demo building

The building selected for deep renovation (Figure 1) is a two-storey timber-frame building from 1971, with only minor later upgrades, owned by Boligbygg Oslo KF. The building contains in total eight apartments, each with a floor area of approximately 42m^2, distributed around two staircases. The building is situated in a suburban area (Haugerud) in Oslo.
The apartments had electrical heating, one electrical heated boiler per apartment and natural (stack) ventilation.

Figure 1a and b. Building before (left) and after (right) renovation. Photo SINTEF (a) and Boligbygg KF (b)

1.2. Introductory condition assessment and premonitoring

An assessment of the technical condition of the building, with emphasis of energy performance, indoor air quality performance and technical renovation needs was performed. Moisture problems were detected, and further examined by partially destructive examination methods. Opening of the wall construction uncovered that the construction of the ground floor external walls differed from the original assumptions, as the main carrying construction was of aerated concrete blocks and not timber frame. Building air-tightness was tested by a blower-door test performed according to NS-EN ISO 9972.

Presence of materials of health or environmental concern was examined by a separate expert surveyor, and asbestos-containing sheets were detected in walls.

Energy performance reports and accounts of previous energy form local electricity provider were collected. Electricity and domestic hot-water usage, airing habits and indoor climate were monitored in four of the apartments for comparison with post-renovation conditions, results are not reported here.

As a supplement to the technical investigations, Boligbygg collected reports of user behaviour and preferences. These showed that tenants often closed the air inlets to avoid draft – often leading to bad air quality – and that preferred indoor temperatures were higher than standard values used in the calculation of building energy demand.

Furthermore, it was concluded that the building needed a renovation of the cladding, and extra insulation to reach a higher energy standard both for walls and roof. The technical systems were old, but functioning, and the electrical boilers were not in a condition where replacement was necessary.

1.3. Renovation concept design

A design team selected by the building owner were contracted at an early decision phase. Expertise on wooden elements and BIM skills were important selection criteria. in addition to architect, consultant engineers and contractor / manufacturer, experts from SINTEF and the specialized element manufacturer Gumpp & Maier were involved in the design process.

Improving energy performance and indoor climate and installing renewable energy, with as little tenant disturbance as possible were important goals for the building owner. Use of prefabricated façade elements with technical integration was decided from the start of the project. Due to the electrical boilers in each apartment and electrical heating, integrated PV panels in the south-facing façade were preferred over solar collectors and energy hub. The electricity from the PVs were primarily to be used for heating and lighting of staircases and operation of the balanced ventilation. The surplus will be sold to the grid because legal restrictions prevent use of produced energy within the apartments

Due to the low loadbearing capacity of aerated concrete, the original idea of wall mounting was not possible, and a new foundation for the elements was included in the concept. Prefabricated roof elements were chosen instead of insulating existing attic to ease moisture proofing of wall / roof all junctions. Existing insulation and cladding were kept, and wind and vapour barriers included in wall elements.

Balanced ventilation with heat recovery was considered a necessary part of the deep renovation to improve indoor air quality and improve energy performance. Several solutions for integration of ductwork were considered. Supply air ducts were integrated in north-facing wall element towards bedrooms, while exhaust ductwork was integrated underneath the stairs. A separate prefabricated element formed as a technical shaft with integrated air handling units (AHUs) was developed. Two apartments were connected to each AHU.

1.4. Contract model

Architect and several of the consulting engineers were selected from providers with framework agreement with Boligbygg Oslo KF. Considering the potential risks in the implementation phase, the building owner wanted to include element manufacturer and building contractor early in the design phase. At first, the search for such were unsuccessful, so more of the design work than intended was performed before the element manufacturer, which also was able to undertake the building works, was contracted in an open-book participatory contract model, with a PV specialist producer as a subcontractor.

2. Methods

2.1. Pre-implementation workshop
Prior to the implementation, representatives of building owner (9), design team (4) and contractor (2) as well as three researchers following the process were invited by the client to a workshop. The process was facilitated by an external moderator with no prior knowledge of the process. After introductory reports of individual experiences from project participation, participants were asked to name important success criteria for the project. The participants were asked to describe "wishes" and "fears" for the building process individually, and then within groups of 4-7 people gather similar risks from the individuals. The grouped "fears" and "wishes" were then placed along two axes according to likelihood and magnitude (positive or negative) of consequences. Based on the results from all four groups, a plan was made in a plenary session to avoid the prioritized fears and realize the wishes. This plenary session was led by a representative of the building client.

2.2. Evaluation workshop and focus group interview
Following the conclusion of the building works, representatives from the design team, building contractor and client were again gathered to a workshop systematizing experience and identifying risks and undesired events, and how they were handled. The workshop was carried through as a focus-group interview. This method is well-suited for exploring attitudes and arguments, and frequently creates new insights when the participants react to each other's input [1]. A semi-structured interview guide that accommodated the participants' own inputs was used. The participants were asked to describe risk management according to phase. The interview was recorded but not fully transcribed. The analysis of the results was based on notes taken during the interview.

2.3. Monitoring and post-hoc experience
A temporary monitoring of indoor CO_2-levels, temperature and relative humidity in living rooms, temperature and relative humidity in sleeping room and supply air duct was set up for four apartments using TinyTag Ultra or Rotronic CP 11 data loggers in a period from December 15th to February, 10th. During the installation and collection of the data loggers, the tenants of these four apartments reported informally about their experience. Only preliminary results of the post-monitoring are reported here.

3. Results

3.1. Risk identification
The risks that were identified and classified into four groups during the pre-building workshop are reported in table 1.

Table 1. Identified wishes and fears, divided into four groups. The scenarios classified as "likely" were prioritized for further work.

	Unlikely	*Likely*
Desirable	Tenants serving cake Nice weather Client adopts solution for all properties No surprises Process according to plan (2) Everything fits	Positive press coverage Interest in the business Transfer of experience to other projects Satisfied client Satisfied tenants (5) No injuries (3) No design-related defects Visually appealing building Delivery on time & budget
Undesirable	Montage failures Technology not working Failing target performance Injuries (tenants, workforce) Damage to VPs Injuries on site (5) Tenant locked in Bad weather Operation problems Connection problems to VPs Negative press	Elements not fitting (7) Delays (3) Problems with ducts Insufficient control of existing cables and installations Unknown technical challenges in existing construction Unknown decay or asbestos Heavy rainfall during building Tenant denying access to apartment

3.2. Risk management plan

A risk management plan (Table 2) to address the prioritized scenarios / targets identified) was produced and responsibility for implementation agreed, as a supplement for the different actors existing routines.

Table 2. Risk reducing actions identified during the pre-implementation workshop

Domain	*Scenario*	*Risk reducing action*
Logistic	Delay at subcontractor / supplier	
	Delay during transport Damage during transport	Sufficient material and manpower for temporary protection of construction. Spare capacity at factory to replace damaged element within set time limit
	Damage to existing cables, pipes, etc.	Available contact info to local electrician plumber, etc. with short response time.
Health and safety	Need to deactivate fire-alarm	Fire guard in place
	Fire escape route blocked	Establish alternative escape route through window
Societal (tenants)	Failure to secure access to apartment	Involve tenants. Inform in relevant language. Information meeting with refreshments in addition to written.
	Annoyance with disturbed power, TV or other signal supply	Inform prior via tenant contact, and during process via signs.

	Injury to occupant	Establish good relations to occupants. Maximum continuity of presence by contractor.
Societal (other)	Neighbours gets hurt or interferes with building	Inform all tenants in neighbourhood about planned work
	Negative public impression of project	Information activities planned, using press and social media. Defined information responsibilities and strategy. Focus on effect and total economy – not costs.

3.3. Preliminary monitoring and informal user feedback

Preliminary monitoring results indicated that living-room temperatures were within 20-26 °C interval in 85 – 100 % of the monitored time period, while CO_2 levels were below 1000 ppm for 94-100 % of the time. Outdoor temperatures in the period varied between -13.4 and 10.1 °C, average 2.7 °C.

During the installation of logging equipment, two of the occupants reported improved thermal comfort, while one occupant complained that the supply air had to be blocked due to strong odour from tobacco smoke.

3.4. Evaluation workshop

The experiences form the installation phase from the evaluation workshop is summarized in table 3. Undesired events in the implementation phase included delayed supply of wooden cladding, water damage to one apartment due to heavy rainfall, delays of work due to presence of one occupant in an access-restricted area and need for mitigation of a damaged asbestos-containing board.

Table 3. Summary of experience as reported in the evaluation workshop

Positive experience	*Improvement potential*
Elements successfully installed Zero injuries Successful integration of PVs, including transport Efficient installation without scaffolding, building crane and minimal temporary installations. Exemplary handling of elements, even with narrow construction site No problems with tolerances to existing walls, placing of windows and existing inlet air openings No problems with conjunctions to other elements, roof elements or elements with ductworks. Successful dismantling of existing windows, to maintain fire escape routes. Minimal need to relocate tenants High tenant satisfaction Short time for actual mounting of elements, acceptable overall progress. Good communication – common targets	Massive time-use for detailing Delays at subcontractors and materials suppliers Long and complicated list of owner demands Method for temporary moisture protection Continuity on site On-site access to drawings (plan / details) More attention to report on hazardous materials and substances, which described location of asbestos Time use for implementing health and safety routines by subcontractors (Location of) cables, pipes and ducts

4. Discussion

4.1. Risk reducing activities prior to implementation
Several of the participants repeatedly emphasized that there was a high degree of openness in communication, trust and sense of common goals between the actors in the design and building phase of this project, and that this was an important for successfully tackling the design challenges. It is beyond the scope of this paper to discuss the importance of these factors for successfully reducing risk by achieving good and robust design, but previous research[2] have concluded that trust is important for group efficiency. Neither do we attempt to assign these *factors* to prior collaboration between participants in the design team [2], the type of contract [3], the fact that the project was perceived as ground-breaking, or any other possible causes suggested in the literature [4, 5].

Since the EU-project had quite specific targets for reducing energy demand and operational costs, a pre-monitoring process fed more information into the design team of the pre-renovation state of the buildings than what may be generally available. Also, cooperation with the researchers following the project may have contributed with risk-reducing information to the design process. As an example, researchers from SINTEF Building and Infrastructure were able to provide specific information on the interpretation of legislation on fire safety, thus reducing risks of not achieving necessary permits.

4.2. Risk identification process
The method of including both desirable and undesirable events in the risk identification process may have contributed to a broader perspective on what kind of events and consequences that needs consideration than a process only examining the unwanted. Statement of desires such as "winning a prize", "satisfied tenants" or more jocular "tenants serving cake" would quite likely have been missed if solely undesirable events were included and brings attention to positive aspects and end goals of the process. Also, the inclusion of tenant contacts and maintenance workers may have strengthened the focus on societal risks and the long-term perspective in the risk assessment.

4.3. Risk classification and adequacy of countermeasures
The method of classifying "fears" and "desires" into four categories could be regarded as a crude simplification of the method of assigning probabilities and consequences of all scenarios in quantitative risk assessment procedures[6]. All registered undesired events identified during the evaluation (section 3.4. were actually identified during the workshop. The risk of asbestos-containing material was not prioritized in the workshop, while the countermeasures against water-damage from rain and missing supply of components were prioritized, but the actions were inadequate to prevent consequences. The presence of an occupant in a restricted area had minimal consequences, as the person was detected, and proper adjustment of work progress could be made.

4.4. Cost and benefit of risk assessment and countermeasures
It has been described a number of psychological mechanisms influencing the perception of risk that in turn could lead to "wrong" allocation of resources for prevention, see [7] for a popular account and [8] for critical discussion. One such mechanism is that risks related to novelties and unusual circumstances may be given undue emphasis compared to well-known factors. A possible example from the described case may be that a high number of participants identified "elements not fitting" as a scenario of high concern, even if measurements in addition to the laser-scanning used for making the BIM were taken at least twice and plans to make smaller adaptations were in place. We have not attempted to specify costs for the risk identification process, the specific countermeasures or the actual costs of repairing the water-damage or mitigating the asbestos and are thus in no position to analyse cost and benefit in the actual case.

4.5. Recommendations for similar projects
To successfully manage the implementation-phase risk of deep renovation of dwellings without relocation of occupants using prefabricated building elements, we recommend workshops or similar processes involving design team, contractor, owner and end-user representatives in order to identify and manage any risks not being mitigated by the design and the operational procedures of the contractor. We further recommend that steps are taken to ensure that scenarios involving occupant or neighbour behaviour, logistical challenges and possible unknown building or installation properties are emphasized during the project. The process should ensure that not only peculiar features of the analysed project, but also well-known risks from other projects and activities are included. A question on "what problems have we experienced earlier in renovation projects?" could be beneficial. The authors stress that the recommended procedure does not replace the need for a thorough condition assessment prior to selection and design of the deep renovation method.

5. Conclusion and further work
The project was able to successfully demonstrate that the concept of renovating low-rise timber-based apartment buildings using prefabricated elements with integrated photovoltaic panels and ventilation ducts as well combined with heat-recovery mechanical ventilation was possible, and that installation was possible with minimal disturbance of the tenants.
The risk management procedures used in the building phase identified several realistic scenarios, and succeeded in reducing, but not avoiding, consequences of rain intrusion, interference with asbestos-containing materials and failure in delivery from materials suppliers. The inclusion of a broad range of participants in the process of identifying risks and opportunities resulted in a risk management plan adapted to the peculiarities of the actual project, with particular emphasis on societal risks and consequences.

Completion of the commissioning process and post-monitoring of energy use an indoor climatic quality will reveal whether the targets of reducing energy demand by 60 % and operational costs by 15 % were achieved, as well as any yet undetected functional flaws.

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7. References

[1.] Morgan, D.L., *Focus Groups as Qualitative Researc*. 1997: Sage publications.
[2.] Buvik, M.P. and M. Rolfsen, *Prior ties and trust development in project teams - A case study from the construction industry.* International Journal of Project Management, 2015. **33**(7): p. 1484-1494.
[3.] Eriksson, P.E. and M. Westerberg, *Effects of cooperative procurement procedures on construction project performance: A conceptual framework.* International Journal of Project Management, 2011. **29**(2): p. 197-208.
[4.] Bygballe, L.E., M. Jahre, and A. Swärd, *Partnering relationships in construction: A literature review.* Journal of Purchasing and Supply Management, 2010. **16**(4): p. 239-253.
[5.] Hosseini, A., et al., *Project Partnering in Norwegian Construction Industry.* Energy Procedia, 2016. **96**: p. 241-252.
[6.] Kaplan, S. and B.J. Garrick, *On The Quantitative Definition of Risk.* Risk Analysis, 1981. **1**(1): p. 11-27.
[7.] Kahneman, D., *Thinking, fast and slow*. 2012, London: Penguin Books.
[8.] Aven, T., *On the allegations that small risks are treated out of proportion to their importance.* Reliability Engineering & System Safety, 2015. **140**: p. 116-121.