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Collect your Retrofits: Parametric modelling to support homeowner energy retrofits in heritage buildings at the early design stage

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Abstract

The joint deployment of energy reduction actions across multiple buildings at once is much needed to reach climate targets, but collective decision-making with shared ownership is a complex process. Each homeowner is accountable for their own energy use, while being constrained by their personal financial capacity and will to act with other co-owners. At the same time, decision-making for energy retrofits involves multiple constraints and criteria, relating to divergent and sometimes conflicting technical, environmental, economic, and social issues, leading to a fragmented response to the retrofitting challenge. This article presents a community-led approach to energy retrofit based on parametric modelling and design space exploration. The approach was tested under the conditions of a homeowner association residing in a heritage building in Amsterdam. Cards displaying each retrofit option and its associated impacts in terms of costs, operational carbon emissions, and energy performance were designed to facilitate negotiation between the participants and their interaction with the computational model. The intention was to empower the group by enabling the exploration of various design alternatives and to nourish conversations about sustainable retrofitting that would normally not take place. Participant feedback shows that the approach effectively improved the quality of the discussion and increased their understanding on the pathways to make their building more sustainable. This article presents the Collect your Retrofits project and describes the potentials and limitations of using parametric modelling to facilitate group decisions made at early stages of retrofit design.

1. INTRODUCTION

The energy transition is a highly complex technical and societal challenge, coping with existing ownership situations, intrusive retrofit measures, slow decision-making processes, and uneven value distribution. Large scale retrofitting activities insulating multiple buildings at once is much needed to reach the climate targets of reaching a reduction of 3.4 million metric tons of carbon dioxide (CO_2) emissions for the built environment by 2030 (RVO, 2020). Current insulation practices of such scale are only executed by single owner buildings, such as housing corporations and large private investors. About 70% of the Dutch housing stock is composed of owner-occupied houses and 1.5 million homes are part of an association of co-owners (in Dutch: Vereniging van Eigenaren or VvE) (CBS, 2018). Each dweller is accountable for their own energy use, while being constrained with their own financial capacity and a shared will to act with other buildings co-owners. There is an existing and ever growing split between individualized responsibilities and the collective energy transition, which has led to fragmented scale and scope responses to the energy retrofitting challenges. Aggregating the design process on a building level would allow more systemic decisions to happen and offer the access to alternative types of funding for co-owners.

By 2050, the municipality of Amsterdam wants to reduce CO_2 emissions by 95% compared to 1990 and be natural gas free by 2040. The Heat Transition Vision describes the ambitions for different districts and the pathways to phase out natural gas for heating the existing building stock (Gemeente Amsterdam, 2020). For Amsterdam city centre, the goal is to achieve a 70% natural gas reduction by 2040. However, there is currently no clear roadmap for reaching this target. Retrofitting monumental areas is a challenge, due to various restrictions, and that there is a lack of standardised methods for conducting energy retrofit on heritage buildings. Most toolkits do not provide tailored retrofit solutions specifically designed for building built before 1945 (Seddiki, et al. 2021). Heritage buildings have usually poor insulation and thermal comfort, which can lead to increased energy usage. Obstacles are the affordability and feasibility of implementing energy saving measures while preserving the monumental character of these buildings. Evaluating the impacts of energy retrofits of heritage buildings with poor documentation and fragmented data is difficult, in addition to the complex calibration of the models. There is lack of knowledge on how to upgrade heritage buildings to a lower temperature heat level. Typically, solutions are tailor-made, resulting in long and expensive procedures. Building owners are in need of affordable expert guidance and upfront insights on technical, financial and legal feasibility.

Collect Your Retrofits (CYR) is a research project prototyping new methods to support VvEs of heritage buildings in collectively planning energy retrofits during the initial design phase. Unlike the current system, where each owner is individually incentivized, the goal is to empower VvEs in making collective and informed multi-criteria decisions for energy retrofits while considering monumental restrictions. In the first section, the article gives an overview of the context of the research in the Netherlands. In the second section, we propose a replicable approach for flexibly exploring collective retrofit design solutions. In the last section, we demonstrate the prototypical implementation of this approach on a VvE in Amsterdam city centre.

1.1. Retrofitting owner-occupied housing in Amsterdam

The municipality of Amsterdam counts over 21.140 VvEs, including 74% small size VvEs (up to 5 units), 20% of medium size VvEs (from 6 to 50 units) and 5% of large size VvEs (more than 51 units) (Baas, 2019). The presented approach addresses the energy retrofitting process of small to medium size VvEs. Stages for implementing energy saving measures can be described as follows:

1. When one or more co-owners want to reduce their energy costs or enhance their comfort by making changes to the building, they may independently seek information or consult an expert to write an energy advice report. Often this process coincides with building maintenance, described in a multi-year maintenance plan (in Dutch: Meerjarenonderhoudsplan or MJOP). Non-profit organizations and the municipality of Amsterdam also offer this service, providing free advice and assistance.
2. The energy advice report provides an overview of the state of the building and suggests potential energy-saving solutions. Usually, it comprises a set of multiple options grouped into 3 to 4 packages, ranging from light to deep retrofit. These packages include technical modifications, implementation costs, the estimated impact on the energy bill and subsidies.
3. It is then up to the VvE to debate and vote for or against the predefined packages. The legal deed of division describes the elements within the buildings that belong to the co-propriety, usually the envelope and shared spaces. The minimum vote required for approval is generally a majority of two thirds.

Packages are formed as a combination of expert proposals together with preferences of few representatives of the VvE, who are in charge of the sustainability agenda or in the board of co-owners. VvEs are presented with predefined retrofit packages, which they then either approve or reject. The municipality of Amsterdam, in its role of assisting VvEs with energy advice, offers trainings and courses for VvEs interested in making their building more sustainable (Gemeente Amsterdam, 2023). However, there hasn't been a focus on redesigning the conversation process itself and the necessary information required to facilitate more effective communication among VvE members. In a multi-stakeholder context, it is often challenging to agree on long-term energy saving investments like deep energy retrofits. Building owners may perceive investment in energy retrofitting as too uncertain, due the high costs and vague saving predictions. Split incentive problems may also arise when some owners do not fully get the rewards of their investment, either in terms of costs or comfort. Providing information on the effects of measures plays a central role on the adoption of the solutions and on correcting potential misconceptions (Ossokina et al., 2021). Engaging owners through co-creation approaches, may potentially result in a greater acceptance for retrofit (De Feijter et al., 2019). Research highlighted the importance of integrating the opinions of owners on evaluation criteria when choosing the most suitable retrofit solutions (Medineckiene, 2011).

1.2. Using parametric modelling tools to support group decision-making

Current practices use parametric modelling combined with building energy simulation to evaluate, compare and define best-performing solutions. Parametric tools such as Grasshopper

and Ladybug Tools are able to condense in a single workflow the design logic, the simulation engines and the optimization indicators. Using parametric models help reducing designer's repetitive tasks and allows more integrated process between different disciplines. Instead of creating individual static solution, the modeller captures the logic of the design problem and reproduces it into Grasshopper environment. Rules define the relationships between the geometric elements and their related attributes (Lee et al., 1996). Additionally, rules can integrate design considerations like user preferences, requirements and limitations (Jones, 1992). When looking at energy retrofitting, parametric models can iterate all possible combinations, allowing the user for simultaneous consideration of all solutions and to quicky compare and sort retrofit scenarios that are most interesting. Giving insights on multiple criteria at once increases the negotiation space, which is often primarily focused on budget and payback period. Thanks to this multi-criteria approach, the preferences and motives of co-owners, which are usually not considered in refurbishment software and design tools (Kaltenegger et al., 2022), can be efficiently utilized. The parametric nature of such models allows replication while keeping a high degree of detailing and customization which is key for heritage buildings.
5 typical stages of the decision-making process for energy retrofitting can be identified: "Considering", "Planning", Decision", "Executing" and "Experiencing" (Ebrahimigharehbaghi et al., 2019). The present research addresses the first stage "Considering" of the decision-making process, where co-owners recognise and identify specific problems in their homes and search for information on how to best solve them (Blackwell et al. 2006, Solomon et al. 2014). The present project is putting in place the scaffolding for a scalable model of simulation-based retrofit measures through so-called "augmented negotiations". In the playful form of a physical card game, complex multi-criteria modelling was translated into an inclusive medium, accessible not only to experts in retrofitting, but every citizen. The intention was to empower the group by enabling the exploration of various design alternatives and to nourish conversations about sustainable retrofitting that would normally not take place. By using this approach, the process of retrofitting evolves into a collective problem-solving challenge, where each individual preference is considered. The focus was therefore on shaping a process for energy retrofitting as a non-zero-sum game, where one's win does not necessarily mean another's loss. The approach was developed under real conditions of a VvE in the historic centre of Amsterdam.

2. MATERIALS AND METHODS

2.1. The CYR approach

The CYR approach focuses on structuring a process that integrates both technical information related to retrofitting using energy modelling tools and the individual preferences within a VvE at the early stage of design exploration. The approach is composed of 3 distinct steps, as illustrated on Figure 1.

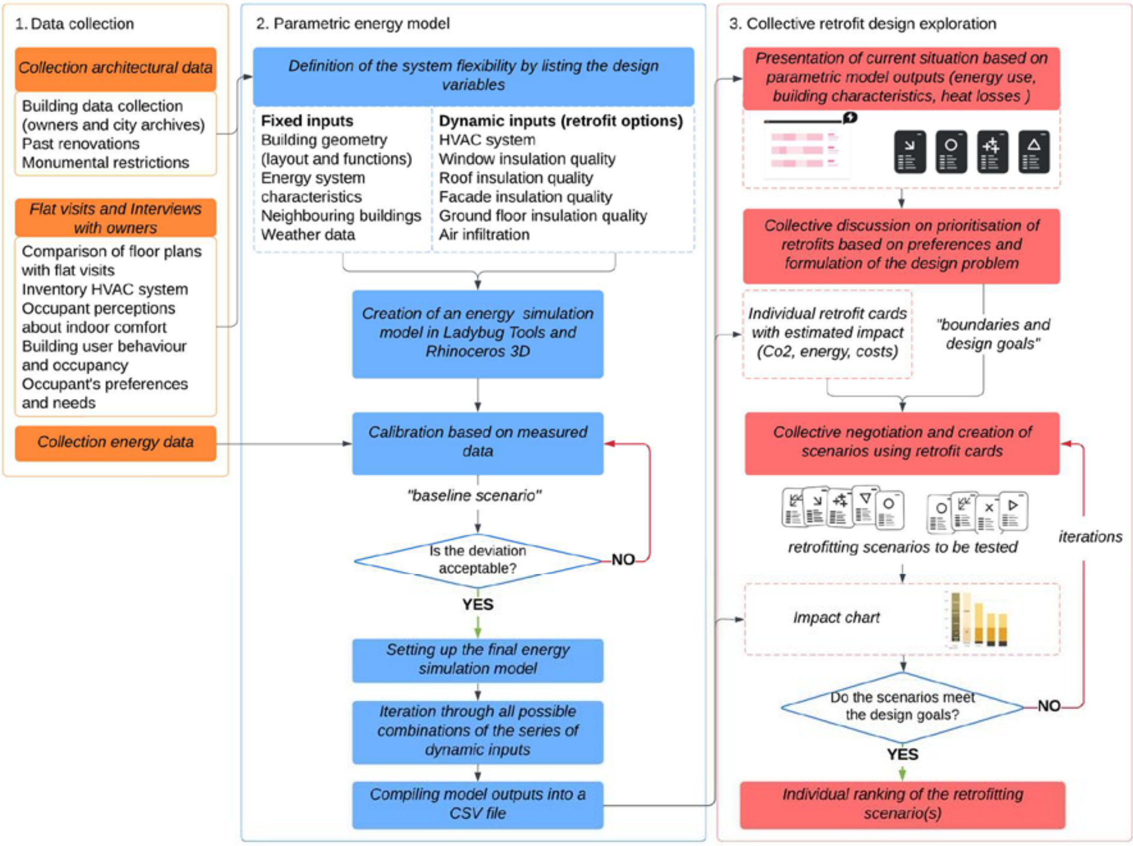

Figure 1. The CYR approach

1. *Data collection:* architectural data such as floor plans, building materials and past renovations were collected from the residents and the city archives. Interviews of the residents were conducted on potential building improvements, indoor comfort and typical use of the building (e.g., ventilation, heating set point temperatures and occupancy). Monthly energy data were collected per unit to calibrate the model.
2. *Constructing a parametric energy model:* by combining geometry of the building, the results of the interviews and simulation engines (OpenStudio and EnergyPlus), the consortium developed a parametric energy model, which calculates all potential energy retrofitting scenarios. For each individual or combination of measures (e.g., post-insulation, equipment upgrade), the model provided insights on the potential impacts on cost savings, energy savings and reduction of operational CO_2 emissions. The model also assessed if the building was ready for lower temperature heat based on annual space heating demand and the peak heating demand in living rooms. Retrofit options, defined as design variables, were subsequently filtered based on technical feasibility and monumental restrictions.
3. *Collective retrofit design exploration:* A workshop with a VvE was organised to allow

the group to interact with the model. Based on the data collected and generated from steps 1 and 2, the research consortium presented the current status of the building, the energy use and discomforts formulated during the interviews. VvE members shared their preferences and motivations for retrofitting and had the opportunity to ask questions to a retrofit expert present in the room on the available options and how the technology functions (e.g., heat pump, ventilation, radiative panels). The VvE collectively defined the design problem, establishing boundaries and goals, such as enhancing thermal comfort on the top, reducing energy expenses, or maximizing return on investment. They could select retrofit options from a set of cards and discuss upgrades to different parts of the building envelope and on the heating and ventilation system. When the group was ready to evaluate a retrofit package, they had collectively assembled, an impact chart displayed the combined outcomes (e.g. savings on costs, energy and operational CO_2 emissions, along with the investment and subsidies). Finally, they could refine their scenarios until they sufficiently aligned with their design goals. Following this iterative process, they gradually narrowed down the solution space. At the end of the workshop, each VvE member individually rated the final scenarios. Few weeks after the workshop, the VvE received a summary of the session and an expert advice with best-performing concepts to get the building off-natural gas.

2.2. Strategic design of the communication media

Two communication media were used to translate the results of the energy model and to support the VvE in creating the retrofitting scenarios: physical cards representing individual energy saving measures and an impact chart indicating the financial and environmental performances and costs of the scenarios. Designing these media followed successive iterations:

1. Beta testing: a preliminary prototype was developed based on literature review (scientific publications and best-practices) and tested with a group of researchers, leading to revisions and improved visuals.
2. Expert workshop: input was provided by behavioural economists, energy advisors, and strategic designers to further refine the prototype.
3. Real-world testing with a community in Amsterdam Centrum: suggestions included the hierarchisation of redundant information like operational CO_2 emissions, or the ability to be able to compare different scenarios outputs.
4. Final application in a VvE in Amsterdam Centrum.

The final design of the communication media is shown on Figures 2 and 3.

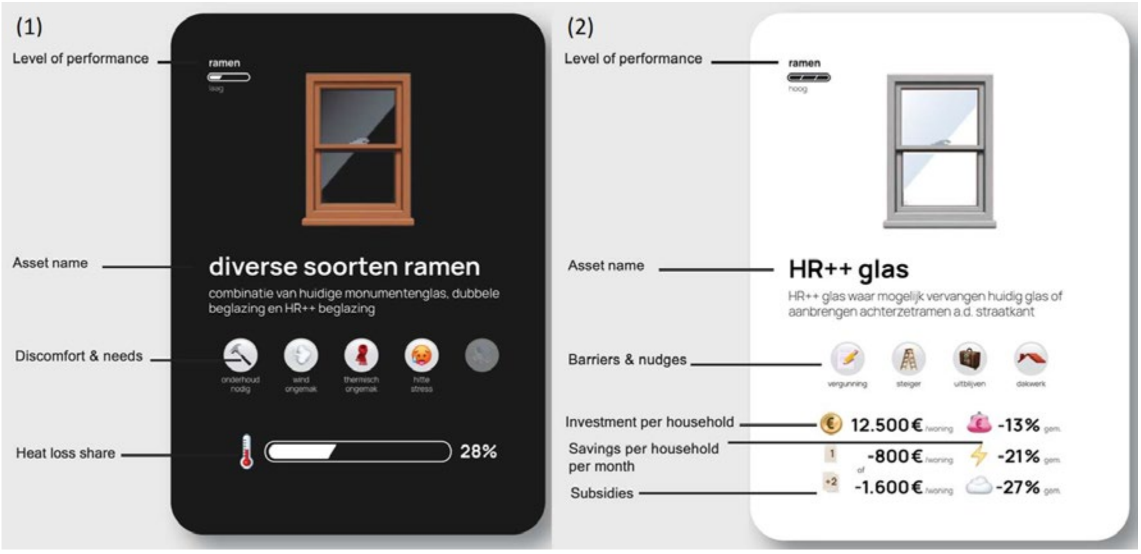

Figure 2. Design of (1) the "black cards" display the current status of the building per element and (2) the "white cards" display the retrofit option and related impacts.

"Black cards" reflect the current situation of the building. An illustration is presented for every building element, ensuring that all participants have a clear understanding of the card. The level of performance indicates the level of performance of the asset. Based on the wishes and complaints collected during the interviews, discomfort and needs are identified to the specific building element (e.g., the need for maintenance, causing wind drafts, causing thermal discomfort, causing overheat, causing noise complaints). This helps co-owners to transform specific concerns into actionable measures. Based on the energy model results, an assessment is made on the share of heat loss attributed to this specific component, which helps to understand the importance of an element over another.

"White cards" represent the individual energy retrofit option. To put in place the measures, some retrofits require more specific actions or specific invasive aspects, which includes permitting, external scaffolding, moving out for a specific time period and roof work. Barriers and nudges show to VvE members that some actions can be combined in time to reduce these barriers. The cost of the retrofit option includes value added tax and installation and is divided per household. Available subsides are shown separately from the investment costs. This is made to act as a visual discount that is an oftentimes compelling argument in behavioural economics. Finally, there is an estimation of operational savings, like utility bill, energy, and operational CO_2 emissions savings based on the energy model. VvE members are told beforehand that these savings can be simply added between cards as it is not linear. This acts as an indication of the importance of impact of a measure.

An impact chart summarizes the impacts of the generated scenarios compared to the current status (Figure 3).

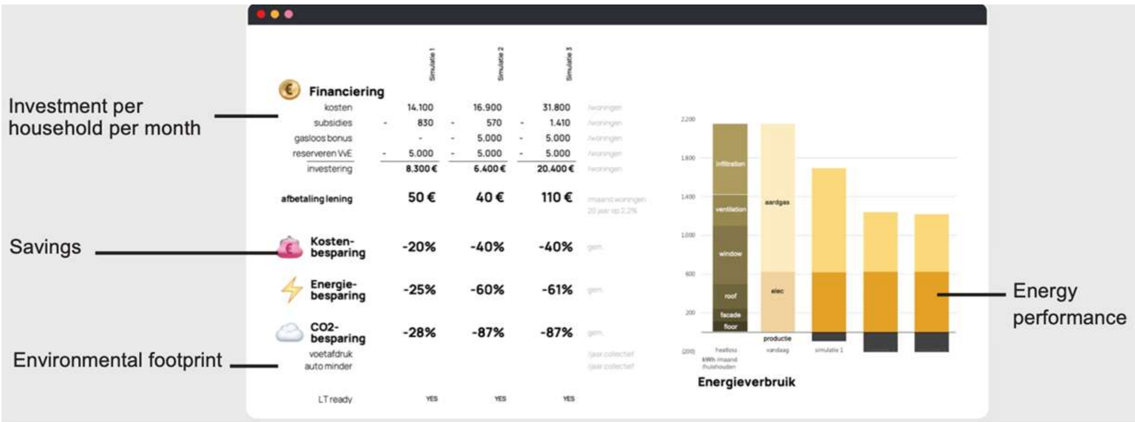

Figure 3. Impact chart comparing the base scenario and three different retrofitting scenarios

A set of costs is presented: investment costs as the sum of the costs written on the cards, the available subsidies and additional natural gas-free bonus (separated to act as a nudge), capital reserves of the VvE and total resulting costs per unit. As the previous number is rarely paid upfront in cash, breaking down the number into what it would mean for a monthly repayment per unit is a more graspable number, closer to the reality of owners. Also, it allows them to compare with the estimated savings on their energy bill. The indicated savings are average of the overall, which do not represent the differences of energy savings between the floors and do not reflect the shares in the deed of division (e.g., big apartments have larger shares, so greater investment are required). A chart is added as a visual indication of the energy savings: it showcases the energy demand in kilowatt hours (kWh) of the existing situation compared to the tested scenarios. This allows VvE members to appraise current versus projected situation and to assess different scenarios visually.

3. RESULTS

3.1. End designs

The VvE that tested the approach consisted of four units in one building: three owner-occupiers and one social housing unit from a housing corporation. The workshop counted four participants: including two owner-occupiers, a representant of the housing corporation, and the tenant of the social housing unit. One owner-occupier was not present. Following the introduction of the current building status and the retrofit cards, the group asked several technical questions on the implications of implementing certain measures (e.g., heat pump, balanced ventilation with heat recovery). Generally, there were concerns about the preservation of the building's historic windows and frames and the feasibility to use vacuum glass or a rear window system with HR++ glazing. Two owner-occupiers wanted to replace their ageing natural gas boilers and steered the discussion towards a collective investment in a shared heat source. Since purchasing a collective heat pump requires all units to be sufficiently insulated, upgrading glazing, roof insulation and reducing air infiltration were interesting options. In general, discussions focused on costs and the monetary benefits of implementing measures and little attention was paid on energy and operational CO_2 emissions savings. One complexity for participants was to consider and accept that certain measures imply requirements, like for instance installing a heat pump without adequate insulation of the building, or extensive insulation would require installing mechanical ventilation. At the end of the session, three scenarios were kept: (1) HR++ glass and 15 photovoltaic (PV) panels, (2) seams and crack sealing, 50 PV panels, mechanical ventilation with heat recovery, collective air-source heat pump, and (3) same as (2) plus roof insulation combined with greenery (Figure 4).

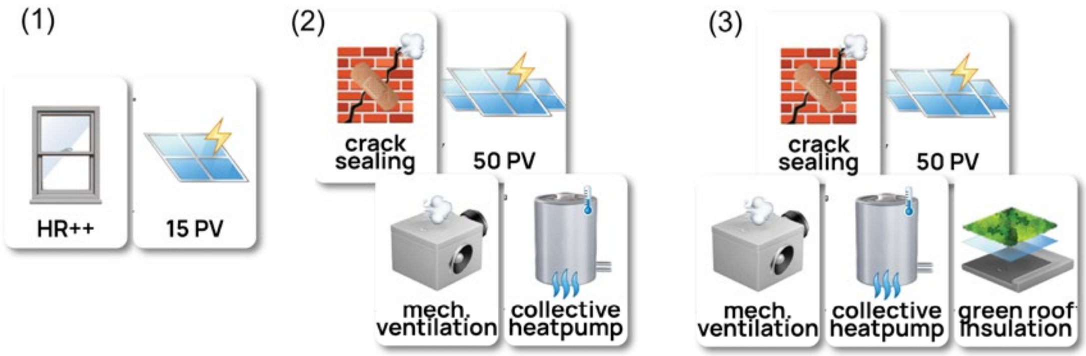

Figure 4. The three end scenarios formed by the VvE

The end scenarios were more ambitions than the results of the interviews, during which members of the VvE were most interested in installing PV panels or green roofing. Based on individual ranking, scenario 2 was most preferred with 55% of the votes against 24% for scenario 3 and 21% for scenario 1. This scenario results in 60% energy saving potential compared to the current energy demand. Using one interface with physical cards and the impact chart accelerated the group discussion and made retrofitting measures more tangible for the VvE members. However, the current setup which starts with the selection of the retrofit options led the participants to create scenarios without a clear understanding of the potential outcomes. This process lacks a systematic approach, with participants essentially hoping for favourable results. A two-ways approach: starting from the retrofits or from the design objectives would be a more effective approach to create optimal scenarios in a short amount of time.

3.2. Participant feedback

At the end of the workshop, the four participants answered a questionnaire, evaluating different aspects of the CYR approach. Participants found the workshop informative, fun and not effortful. They felt that the design of the cards was inviting and that the objectives of the session were clear. One person reported that “the cards make the situation tangible”. They were satisfied with the final scenarios and would recommend the process to other VvEs. Although one participant reported conflict, they agreed that it was easy to interact with other VvE members, and that it generally helped them to understand each other better. In general, they found that there was enough information and that the impact chart could be more simplified in monetary terms with, for instance, a preliminary overview of the most optimal scenarios. Further results are summarised on Figure 5.

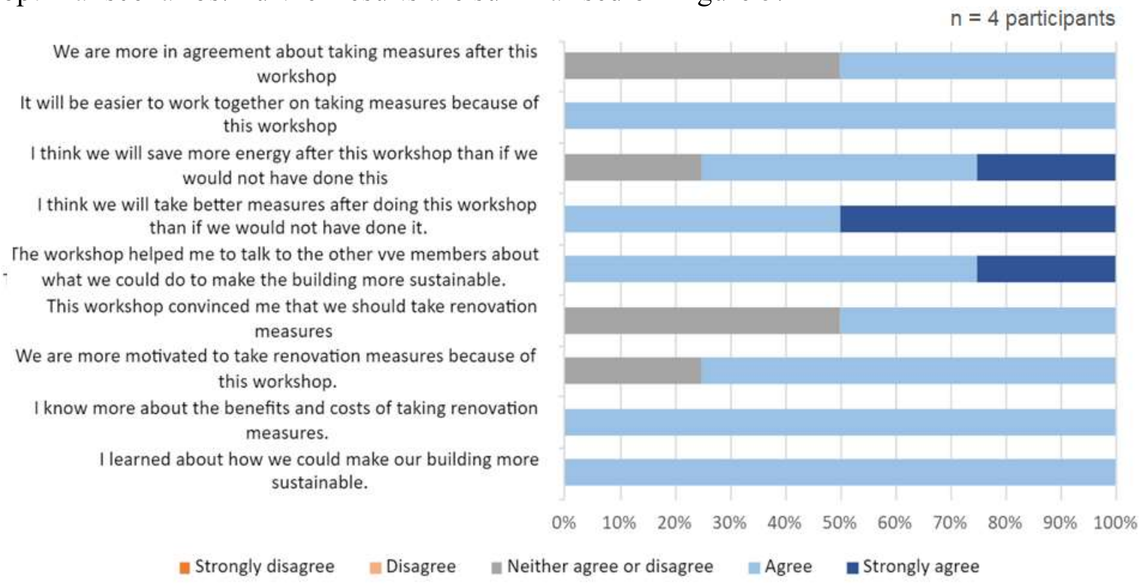

Figure 5. Participant feedback on the CYR approach

All participants said that they would use the results to take future decisions for making their building more sustainable. As improvement note for future sessions, they recommended to take into account all potential obstacles such as policy of housing corporations and to invite a subsidy expert.

4. CONCLUSIONS

Key learnings: The CYR approach proved to be versatile for the fast generation of scenarios and provided quick feedback to the VvE participants. This is an important result, when considering the complexity and time required for VvEs to collect and compare data from different construction companies. The project revealed that real-life experiences and personal preferences can be efficiently integrated when utilizing parametric modelling methods. Additionally, the approach can be used to generate staged retrofitting plans, making propositions actionable by providing insights into the timeline for implementation (e.g., what investments will be needed and when). Despite the multi-dimensional nature of the approach, the VvE primarily prioritized cost optimisation in their designs. Overall, the approach received positive feedback, with participants agreeing that they learnt more about how to make their building more sustainable and that they will take better measures after doing the workshop than if they would not have done it.

Limitations and scalability of the approach: To overcome conflicts arising from split

incentives, it is essential to build capacities for collective reflection and action. Forming scenarios is a very complex process, requiring the active participation of all co-owners. In the current form, the proposed design exploration process relies on some parts on the knowledge of a retrofit expert present in the room, making difficult for VvEs to run the experiment independently. The CYR approach is tailored to the specific building situation, enabling the generation of precise results when compared to the standard archetype-based approach. While the parametric logic can be easily adapted to other VvE cases, recreating building's geometry is time-consuming. Information on past renovations in heritage buildings, including building materials and existing equipment is fragmented with often only scans from city archives available. This means that data is shared partially, requiring validation with flat visits and interviews of the VvE members. It would be interesting to integrate Historic Building Information Modelling (H-BIM) technologies using point cloud to generate geometry more efficiently. Collective interventions, as not the norm, lag in terms of reliable technical information, available subsidy, or market supply and installation. The entire 'ecosystem' is not ready for approaching retrofit collectively.
Recommendations for future research: The retrofit scenarios should directly relate to the MJOP of the VvE to make the end proposal actionable. Savings of the general maintenance plan are not integrated while it is one of the aspects that is currently the most cost savings. The desirability of the solutions and their impact on heritage significance could be more detailed: looking at different scales of impact; from area to ensemble, to building, to building elements. Retrofit costs are a limited value of the approach, since this indicator is very uncertain and dependent on the implementation of the measures, material availability, installation capacity and energy prices. Future research should also incorporate embodied carbon of insulation and energy payback time as a performance metric. Last but not least, it would be interesting to analyse how the CYR approach influences changes in behaviour, and to what degree the early involvement of co-owners in co-designing retrofitting plans is key in encouraging more ambitious energy retrofit decisions.

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