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Local recycling and reuse of concrete and soil: The societal impact of double-loop learning from circular urban transformation projects

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ABSTRACT

The article presents certain findings from a large European research and development project aiming to generate societal impact through multi-stakeholder collaboration based on circular economy principles in the built environment. In the project, eight apartment buildings were demolished, and recycled aggregate concrete was used to cast the foundation for a new city hall being constructed nearby. Additionally, excavated soil from the construction of the city hall was transported to the urban development site where apartment buildings had been demolished, and the excavated soil was used in the terrain for the new urban development in the area. The local reuse of excavated soil significantly reduced transport volumes as the soil would otherwise have been transported long distances out of the city. The primary impact of the project was the direct environmental effects associated with the local concrete and soil recycling. The secondary impacts were linked to improved coordination and management of circular construction projects in the municipality through knowledge and competences being developed during the project (single-loop learning). Finally, the project also created awareness in the municipal organisation about strategic and organisational changes needed to facilitate future circular construction projects (double-loop learning).

SPECIFICATIONS TABLE

Subject area	2311 - Waste management and disposal
More specific subject area	The article covers multiple disciplines and subject areas related to circular economy, waste and sustainability. It describes the impacts generated from a project on recycling and reuse of construction and demolition waste adding to the existing body of knowledge about recycling practices in the build environment. Additionally, the article reflects on single-loop and double-loop learning processes that finds its theoretical roots in organisational learning studies.
Category/categories of societal impact	Environmental Political Societal Technological
Sustainable Development Goals (SDGS) the research contributes to	*GOAL 11: Sustainable Cities and Communities* *GOAL 12: Responsible Consumption and Production* *GOAL 13: Climate Action*
Resource availability	-
Related research article	-
Stage of research	*The article demonstrates the achieved and documented societal impacts of the project.*

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Social impact: single-loop and double-loop learning

The construction and demolition sector in Europe generates approximately 800 million tonnes of waste every year, representing more than one third of all waste generated in Europe. Most construction and demolition waste (CDW) is crushed and used as backfilling in road constructions. Transport associated with the movement of CDW and soil to and from construction sites accounts for approximately 10 % of CO^2 emissions during the construction phase [7], and the construction logistics have been overlooked as a measure to increase productivity and reduce environmental impact. There exists a significant societal

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potential in improving waste management practices to reduce pressure on scarce materials and in reducing climate and environmental impacts [5,8]. To achieve this potential there is a need to develop demonstration projects to overcome legal, technical, and behavioural barriers [4]. The transition towards circular economy is a complex task that requires reordering of technological, social, economic, and political arrangements in our societies [10]. It also entails activation of knowledge from many disciplines and in many forms. Consequently, co- production of knowledge [3] has become a key approach to especially impact- driven research in which researchers and practitioners collaborate to develop knowledge, which can drive change. Co-production covers the ambition to engage multiple stakeholders targeting various societal impacts. The outcomes of this project can be distributed between *direct* impacts and *indirect* impacts that were generated from the knowledge and experiences generated during the project and its long-term effects on the involved organisations. To conceptualise the indirect impacts of the co-produced knowledge, we distinguish between single-loop and double-loop learning. The core idea behind double-loop learning was initially developed by Chris Argyris [2]. Argyris defines single-loop learning as the processes where knowledge is used in organisations to detect and correct errors to improve present tasks and activities, whereas double- loop learning refers to processes where knowledge is used in the organisations in ways that question underlying policies and objectives to foster transformative change. The original idea has been further developed in later research to include also a third loop focusing on learning processes in which entirely new methods for problem-solving are generated [1,6,9]; however, an empirically tested and validated distinction between triple-loop and the original single-loop/double-loop learning is yet lacking [9].

Methodology: co-production of circular solutions

The CityLoops project is an EU-funded research and development project (Horizon 2020) in which 35 partners from 7 European cities (Porto, Apeldoorn, Mikkeli, Bodø, Seville, Roskilde, and Høje-Taastrup) have collaborated to co-produce circular economy solutions and instruments for CDW (and bio-waste). A core part of the project was a series of demonstration projects. This article presents the results of the demonstration project taking place in Høje-Taastrup, Denmark, aiming to develop and test procedures and practices for recycling of concrete waste and soil from large- scale demolition projects and to embed these experiences in municipal planning and decision-making practices. The local Danish project consortium include Høje-Taastrup Municipality (Environmental Department), Roskilde Municipality, Gate21, the Capital Region of Denmark, Danish Association of Construction Clients, and Roskilde University.

The role of the university partner was: first, to assist the municipality with knowledge inputs during demonstration activities; second, to collect data during the demonstration activities; and third, to co-produce knowledge about improvements to planning and decision-making activities. The authors closely followed the process throughout the entire project period, as well as the decisions- making activities that took place internally and externally in the municipality. In collaboration with the municipality, two workshops were planned and held, followed by eight interviews that were transcribed in-situ with employees in the involved departments and with external stakeholders who all played a key role in the demolition of Taastrupgaard and the construction of the new city hall in order to evaluate the project. Additionally, relevant documents from the construction process were collected and analysed, such as the tender material, to provide an in-depth insight into the construction and demolition actions.

Results and implications: construction of the new city hall

The demonstration project aimed to recycle concrete from the demolition of eight apartment buildings in the construction of a new city hall and to reuse soil generated in the two construction and demolition projects. The activities took place between 2016 and 2021 and involved multiple actors along the construction and demolition value chain. The demolition of the eight apartment buildings was a part of an urban transformation project designed to overcome challenges in social housing areas. The buildings were a part of the so-called Taastrupgaard and built in the 1970s as a social housing area covering approximately 1000 housing units. The aim of the demolition was to make room for a new school, day care facilities and a cultural centre, and soil from the construction of a city hall was to be used to model the terrain around these new buildings. The demolition took place in 2019 and generated a total of approximately 25,000 tonnes of recycled aggregate of which 10,000 tonnes were intended for recycling purposes. As a result of the demonstration project, 4000 tonnes were used as stabiliser in the construction of the new cultural centre in Taastrupgaard, 2000 tonnes were used as stabiliser in construction projects near the new city hall, and 1088 tonnes were used as recycled aggregate to cast the foundation for the city hall. The CityLoops project focussed on the recycling of concrete and soil between the city hall and the Taastrupgaard projects.[1] Several companies were involved in the process (as shown in Table 1).

The demolished buildings were owned by the social housing company KAB, and the demolition was carried out by the demolition contractor Søndergaard Nedrivning who received the demolition contract after a tendering process. When tendering the demolition project, an option was included, that Høje-Taastrup Municipality could receive 10,000 tonnes of concrete for recycling with the intention to use this in the construction of the new city hall. However, this option was not realised in its intended contractual form due to different factors. Initially, the concrete was sorted into different pollution classes and used accordingly. As the demolition project progressed, time constraints necessitated an expedited construction process. This led to a deviation from the initial plan, with all concrete not classified as pure being treated as if it was in the worst pollution class. This decision was made due to the lack of time for sorting. The site had been sold for a different purpose from a certain date, necessitating the completion of the demolition by then. Instead, after a negotiation process, the demolition contractor delivered the concrete to Høje-Taastrup Municipality to use it in the construction process. 1088 tonnes of concrete were provided by the demolition contractor to the waste management facility Norrecco who crushed the concrete and delivered it to Unicon, the concrete manufacturer and supplier. Unicon then included the recycled aggregate in the production of concrete which was deployed by the construction contractor Munck in the cast concrete foundation for the new city hall.[2] The companies were introduced as subcontractors to Nordstern who had the main contract for the city hall. The 6000 tonnes of concrete used as stabiliser was crushed on-site by the waste management company RGS Nordic. The reasons behind these deviations from the intended contractual form would be relevant investigating further, as they could provide valuable insights into the practicality of the contracting processes or potentially reveal other influencing factors.

The concrete used in the city hall foundation was crushed outside the city at a facility belonging to the waste disposal facility Norrecco. On-site crushing of the concrete used in the city hall foundation would potentially have reduced environmental impacts from transport, but it was decided to crush the concrete at a designated facility outside the area due to lack of time, a missing crushing permit, and to spare

[1] A previous project, CleanTechTipp, had already explored the potentials for concrete recycling. In this project the concrete was tested for contaminants (PCB and other harmful substances), and a recipe for concrete production using recycled aggregate from Taastrupgaard was developed by the concrete and aggregate testing company Pelcon. This recipe was afterwards used in the CityLoops demonstration project.

[2] The alternative source of aggregate is likely to have been either a quarry in southern Sweden or from the ocean floor north of Poland.

Table 1
All stakeholders involved in different stages in the project with a brief explanation of their roles and which project they have been involved in.

Stakeholder	Role	Description
Høje-Taastrup Municipality	Client who commissioned the projects	The planning of the new city hall was managed by the Department of Properties and Internal Service (CEIS). The Environmental Department played a crucial role in the planning and decision-making
PLH Architects	The architectural firm	In collaboration with ALL and COWI they designed the new city hall
Wissenberg	Consulting for KAB	In collaboration with the architectural firm Vandkunsten as a sub-consultant, Wissenberg provided total consulting such as technical advice and assistance for the new cultural centre project and during the demolition of Taastrupgaard
Søndergaard Nedrivning	Demolition contractor	The demolition in Taastrupgaard was carried out by Søndergaard Nedrivning who received the demolition contract
Norrecco	Waste management facility	The concrete used in the city hall foundation was delivered and crushed outside the city at a facility belonging to the Norrecco
Unicon	Concrete manufacturer and supplier	Norrecco delivered the crushed concrete to Unicon, who then included the recycled aggregate in the production of concrete, which was implemented by the subcontractor Munck, in the cast concrete foundation for the new city hall
Pelcon	Concrete and aggregate testing	The concrete from Taastrupgaard was tested by Pelcon
KAB	Social housing company	The demolished buildings in Taastrupgaard were owned by the housing association KAB
Munck	Subcontractor	Subcontractor on the city hall project
Nordstern	The general contractor	Nordstern had the main contract for the city hall
RGS Nordic	Waste management company	The concrete used as stabiliser in the new cultural centre and in construction projects near the new city was crushed on-site by RGS Nordic

residents from noise and dust associated with the crushing processes. (Fig. 1).

The decision to build a new city hall in Høje-Taastrup was made in 2016. The existing city hall needed extensive renovation, and the estimated costs associated with the renovation were considered so extensive that the city council opted for the construction of a new city hall. An architectural design competition was completed in 2018. Although multiple stakeholders were involved, the key role was played by Høje-Taastrup Municipality as a facilitator and construction client for the city hall. As a partner in the CityLoops project the mayor had signed a European Circular Cities Declaration, thereby committing the municipality to support and facilitate the transition towards a circular economy. This helped raise awareness and provided a clear political mandate to work towards increased reuse and recycling. The planning of the city hall construction project was managed by the Department of Properties and Internal Service (CEIS), but the Environmental Department played an important role in the planning and decision-making, feeding knowledge on circular economy and potentials for recycling into the decision-making process. The city hall was originally intended to be certified against the DGNB standard. During a workshop on potential initiatives to obtain DGNB points, the Environmental Department suggested recycling of CDW from the demolition of Taastrupgaard, and at the final steering group meeting it was decided, based on inputs from the Environmental Department, to include recycling into the tendering material, specifically encouraging contractors to include recycled concrete from Taastrupgaard in their biddings. Following this process, the winning consortium with the company Nordstern as the main contractor chose to include recycled concrete in the foundation of the new city hall as a part of their offer. The foundation with 100 % recycled aggregate was casted in the beginning of 2021. (Fig. 2).

Alongside the planning of the city hall, the Department of Properties in the municipality had acquired the area previously occupied by the eight apartment buildings in Taastrupgaard with the intention to build a new public primary school. In the area, a large amount of soil was needed to model the terrain. The construction of the city hall would generate large quantities of excavated soil that would otherwise have had to be transported out of the city. As this soil proved to be uncontaminated and geotechnically suitable for the purpose of modelling the terrain, it was decided to reuse 9000 tonnes of excavated soil from the city hall construction project to model terrain in the area where the apartment buildings had been demolished and where the new school was built. (Fig. 3).

Whereas recycling of concrete between a demolition project and a construction project located only few kilometres apart and taking place more or less simultaneously may seem simple, in reality it is a complex task involving multiple stakeholders with diverging economic interests and risk perceptions. The current structures and procedures in the

Fig. 1. View of the Taastrupgaard social housing area with approximately 1000 housing units, highlighting the demolition of eight apartment buildings that were recycled in the construction of the new city hall.

Fig. 2. The construction phase of the new city hall in Høje-Taastrup C, where the foundation with 100 % recycled aggregate was casted in the beginning of 2021.

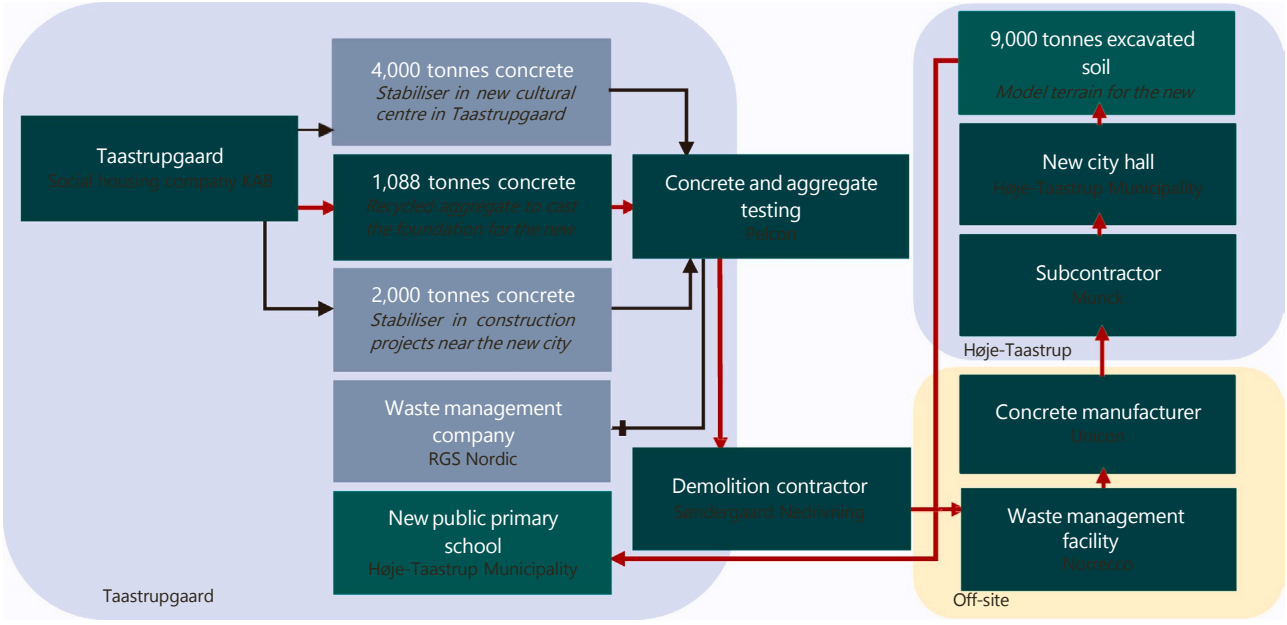

Fig. 3. Overview of the material flows associated with the total amount of 7088 tonnes concrete used in the projects. The black arrows shows the total of 6000 tonnes of concrete, which was used as stabiliser on-site as a part of the new cultural centre including the construction of the new public school. The red arrows explain the reuse of 1088 tonnes concrete transported from the Taastrupgaard area to be integrated in building of the new city hall in Høje-Taastrup C and how the 9000 tonnes excavated soil was transported back and used to model the terrain for the new public school in the Taastrupgaard area.

conventional building sector, based on hierarchies of subcontracts, inhibit innovation and complicate activities which involve introduction of new procedures – as for example recycling of concrete. The empirical data showed how the municipality played a vital role as a facilitator and construction client in the ongoing search for solutions and pathways for recycling and reuse of concrete and soil and as a broker between multiple companies involved in demolition and construction activities in the demonstration project. Internally in the municipality, the Environmental Department played a crucial role pushing the circular economy agenda into planning and decision-making processes. A key lesson learned from the demonstration project is that early introduction of circular economy principles in planning and decision-making increases opportunities, technically as well as economically, and makes the process less vulnerable to fall back into business-as-usual procedures, where CDW is crushed and used as backfilling rather than integrated into construction of new buildings. Another lesson learned is that a municipality as a large-scale construction client do have the bargaining power to influence processes and procedures in the construction sector. However, steering complex construction projects with multiple stakeholders involved requires a clear political mandate, competences within the municipality to identify solutions in collaboration with the involved companies, and a proactive attitude, whereby the municipality actively encourages external stakeholders to search for circular solutions throughout the planning and decision-making.

The twofold social impact appeared in the evaluation of the demonstration project and the empirical data. First, the project generated a direct social impact from the recycling of the concrete and soil. The results demonstrated that it was technically, practically, and economically possible to recycle soil and concrete in large-scale construction and demolition projects. An early introduction of circular economy principles in planning and decision-making would increase opportunities, technically as well as economically, and makes the process less vulnerable to fall back into business-as-usual procedures, where CDW is crushed and used as backfilling rather than integrated into

construction of new buildings. The learning outcome of these activities including the empirical data such as the two workshops can be characterised as single-loop learnings, as it involves learning processes inside and between multiple stakeholders. The departments were to identify, and improve organisational structures and decision-making, which contributed to identifying and developing double-loop learnings by improving the decision-making processes in the municipality. Furthermore, the involved stakeholders co-produced knowledge and developed competences related to existing procedures such as tendering processes, demolition procedures, waste handling, etc. The project also generated double-loop learning in the sense that the involved stakeholders during planning, decision-making, and implementation phases of the project questioned norms, routines, and practices within the organisations and eventually co-produced new knowledge, planning procedures and operational strategies supporting circular economy principles in the built environment. The experiences from the demonstration project in Høje-Taastrup were embedded in the municipality's climate action plan and housing policy and are being integrated into a new sustainability strategy. To further progress it is crucial that the heightened level of competence within the Environmental Department during the demonstration project is embedded in CEIS as public client to systematise processes. However, the long-term effects of the double-loop learning processes could not be monitored and documented within the timeframe of the CityLoops project.

Ethics statements

This journal's Guide for Authors contains detailed information on the ethical guidelines that all authors must comply with. In addition, we ask you to complete the relevant statement(s) below. Please delete those which are not relevant for your data.

Non of the statement(s) are relevant for our data.

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CRediT authorship contribution statement

Thomas Budde Christensen: Data curation, Methodology, Writing – original draft, Writing – review & editing. **Martin Visby Buchard:** Data curation, Methodology, Writing – original draft. **Cecilie Nadine Glarborg:** Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

Cecilie Nadine Glarborg reports a relationship with European Commission that includes: funding grants.

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