Functional diversity in circular building projects

A novel perspective to study actors, roles and circular results

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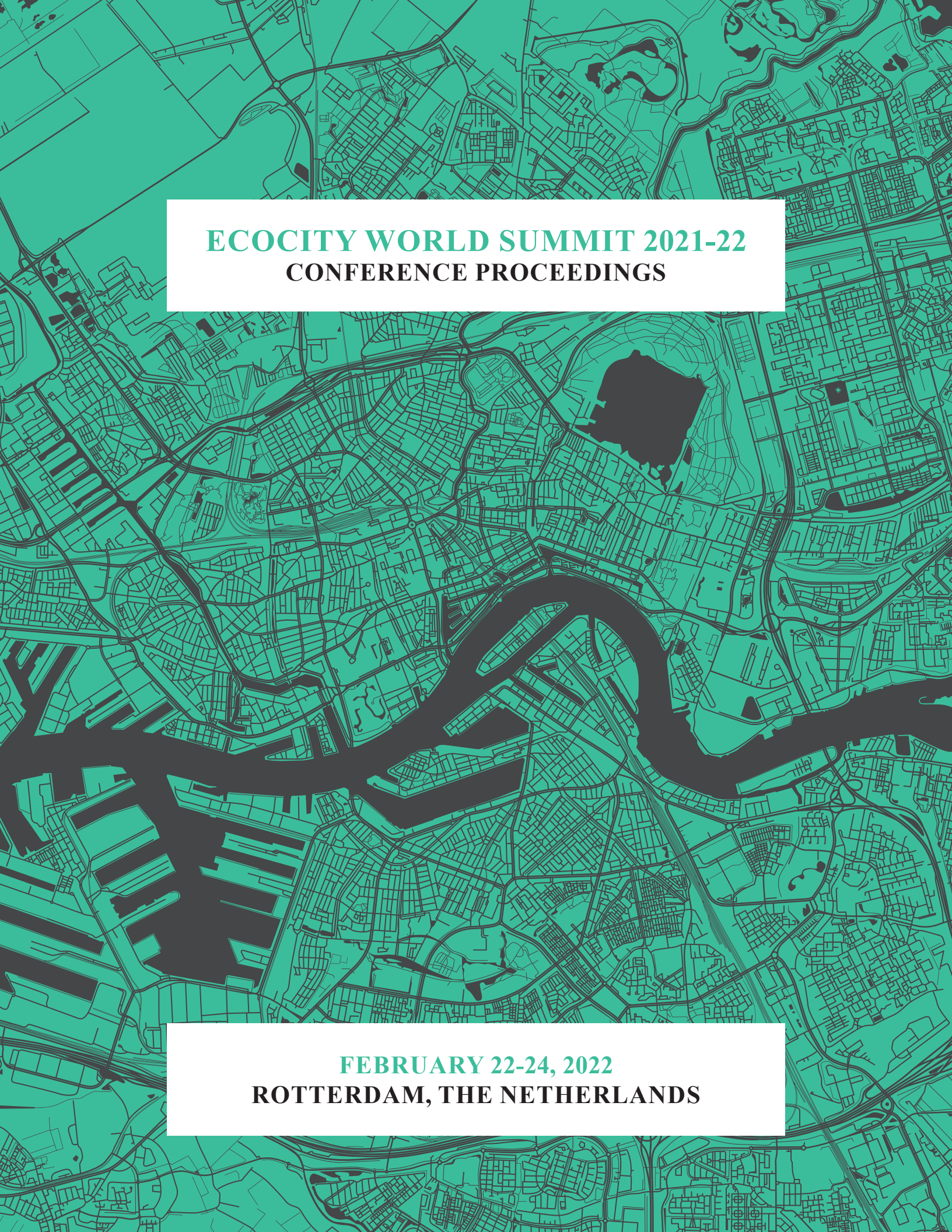

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FUNCTIONAL DIVERSITY IN CIRCULAR BUILDING PROJECTS: A NOVEL PERSPECTIVE TO STUDY ACTORS, ROLES AND CIRCULAR RESULTS

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ABSTRACT

Construction sectors have a long way to go to realize a circular economy. Many organizational barriers and institutional characteristics inhibit the sector's transition to circular practices. Nevertheless, within this early phase of the transition, several building projects were realized. This research aims to learn from these frontrunners, in order to distill insights on how to improve conditions at project level. Drawing on ecological systems metaphor, circular building projects in this research are regarded as a system of multiple actors that each perform one or multiple functions: these functions together make up the functional diversity of circular building project. The sum of these functions produces a system service (i.e. circular building elements). Using this perspective to analyze four circular cases, we uncovered five functions that are crucial to realize circular buildings: 1) connecting though vision; 2) matching supply and demand; 3) providing used materials; 4) constructing circular building elements and 5) controlling safety and quality. The functional diversity perspective reveals that functions are to large extent interchangeable between actors. Further applications of the functional diversity perspective could reveal its relevance to support the transition to a circular construction practice and possibly other transition themes.

KEYWORDS

circular economy; construction; projects; actor analysis; innovation; case study; functional diversity.

INTRODUCTION

The 21st century can be marked by human's reconsideration of the relationship between the fossil-fueled economic system and the planet we inhabit. This is reflected in the enthusiasm surrounding the concept of Circular Economy (CE) over the past 8 to 10 years. Although earlier approaches to the CE exist [1-4], a significant rise in popularity can be recognized recently by the numerous organizations [5] and governments [6] adopting the concept.

One of the sectors in which CE principles can provide considerable environmental gain is the building construction sector [7]. In brief, the transition from a linear to a circular construction sector is aimed at innovations in "the entire chain of production, consumption, distribution and recovery of products and materials" [8], ultimately resulting in a more resource-efficient industry and built environment [9], eventually reducing its carbon footprint [10].

Circular results in the building construction sector

Despite the popularization of the CE concept, the number of constructed building according to circular principles remains small. This situation is caused partly by the building industry-wide institutional characteristics, yet also a variety of more building project related and governance barriers are at play [10-12]. In addition, financial barriers such as the adoption of circular business models [13] and the unproven circular building project business cases [10, 14]. Moreover, segregation of actors involved in different building life-cycle stages seem to be a key cause to prohibiting the realization of circular buildings [15, 16]. Finally, there is discussion going on considering the eco-efficiency and performance of circular products [17] and which to prioritize in the construction sector (e.g. is newly sourced wood better than recycled concrete?). A shared vision on which materials and products should be applied how and where is lacking.

When looking at construction practice, a rise in circular building projects (CBP) can be identified in the past 10 years. These CBP are often small and few in numbers, but none the less crucial for paving the way for institutional change and implementation, by revealing barriers and implications and at the same time realizing more sustainable living environments [6, 18, 19], while fostering innovation in construction [20]. A project-level focus is relevant, as projects form "*the arena where the inevitable process of mutual adaptation of niche an regime take place*", as stated by van Bueren & Broekhans [21]. Processes of refurbishing, remanufacturing, redistribution and reuse imply new activities for established or new actors, such as demolishers who instead of feeding the recycling industry with used materials, store these materials and deliver them back to contractors for reuse. However, there is not a clear understanding on what actors do to achieve these types of circular results in circular building projects.

Recent research on accelerating the transition to a circular built environment lacks a focus on the project level. Studies focus on identifying enablers and disablers at sector-level [22] or from the perspective of one actor in the building-column [23], what circular strategies for different building life cycles are successful [24] and on stimulating a CE from an inside-company perspective [18]. Literature review by Munaro et al [25] confirms a lack of research regarding actors in CBP and how they achieve results. Scientific insights are usually translated to be useful in contexts such as policy making, sectoral transition management or technical design and tooling. As Pomponi & Moncaster [26] propose: *"the greatest challenges ahead lie not in further technological innovation but rather in the role of people, both as individuals and as a society."*

Some studies do touch upon roles and activities when looking at how actors aim to achieve specific results in projects. An example is the role of system integrator [20]. The idea of a specific recurring role in different projects provided researchers a tool to monitor what actors in the sector fulfill this role as time progresses (e.g. [27] & [28]). However, to our knowledge, there are no studies that uncover the apparent functions in circular building projects taking all actors into account, in order to uncover how actors achieve (environmental) results. This research focusses on the changing activities of actors in niches of circular construction projects as to: 1) understand how this may be indicative for sector-level transformation (in line with Wittmayer et al. [29]), and; 2) add guidance for practitioners in the field and their daily work as an addition to what niche innovation theory offers.

Defining the environment of circular building projects

The aim of this research is to understand what actors in CBP do and how these roles or activities are crucial to the actualization of circular ambitions on a project level. To be able to grasp the concept of activities and roles in context of circular construction projects, we follow three main lines of thought:

1. CBP's can be seen as a niche in which innovations are nurtured through activities of actors in these projects. The changing activities of for example a demolisher who feeds resources back towards a building project instead of the recycling industry, can be explained through transition theory, as circular construction projects can be considered a niche (i.e. a protective space) in which innovation is nurtured [30, 31]. Niches are typically seen as crucial elements for realizing a transition of sectors or systems, as they provide the seeds for system transformation [32]. Given the multi-actor nature of transition processes, transitions imply changes in the roles of actors and their relations to, and interactions with other actors [29].
2. This research adopts the term 'function' instead of 'role'. We prefer to use the term 'function' because the term intuitively draws attention to what actors *do* rather than *who they are*. This intuitive nuance is important to encourage a focus on changes in actor activities in CBP.
3. To perform functions, actors engage in activities in CBP. There are different theoretical perspectives on actor roles and related activities. Wittmayer et al. [29] derive three main role perspectives: roles as recognizable activity, roles a resource perspective, and roles as boundary object. Our understanding of functions is mostly in line with the first perspective 'roles as recognizable activity'. In line with this perspective, we understand functions as a recognizable set of activities, or in the words of Turner [33] as "comprehensive pattern of behavior and attitudes, constituting a strategy for coping with a recurrent set of situations, which is socially identified – more or less clearly – as an entity".

Summarizing, this research regards CBP as niches in which actors perform functions through engaging in activities as a strategy to cope with situations that emerge as a result of adopting circular principles in CBP. This leads to a framework called 'functional diversity', which we further develop and present in the chapter 'functional diversity framework', which introduces the novel functional diversity perspective (FDP). The methodology chapter describes the research- and data collection method. The chapter 'circular building project cases' introduces the cases studied, while applying the FDP. Chapter 'functional diversity of circular projects' combines the results of the cases studied separately into five functions, including a cross-case analysis. Chapter six discusses the results and limitations and finally the conclusions are presented.

FUNCTIONAL DIVERSITY FRAMEWORK

Drawing on biodiversity- and ecosystems services theory, we develop a functional diversity framework that helps to identify the functions performed by actors in circular building projects. The science of ecology draws our attention due to the vast array of methods [34] used to analyze organism food webs [35] and populations and communities [36]. Network thinking in ecology arose in the early 1940's, with periodic waves of interest. Research focusses on the architecture of networks, network robustness and methods to compare complex networks [37]. Application of ecological concepts to industrial systems is not new and the field of Industrial Ecology is a good example of this. Especially methods of ecological modelling have been mimicked in new ways to study cities and industrial parks [38, 39]. Network theories regarding species have as well been adopted in industrial ecology, used to reveal the interrelation between actors, resources and activities [40, 41]. The named methods are however quite rational in their description of relationships [16], consequentially lacking the detail to uncover how and why certain elements became part of that network in the first place.

The ecology-science concept of functional diversity specifically draws our attention. This concept has been developed in context of ecosystem services [42, 43] and refers to the collection of functions that form an ecosystem which provides an organism with a certain service [44]. Functional diversity offers a way to analyze the biodiversity present in ecosystems by identifying the functional groups that are necessary for the functioning of ecosystems. It has proven to be an efficient way to identify the dependencies in a larger ecosystem that together form the basis to deliver system services [45].

This approach is popular in ecosystems services theory because it is considered key to understanding ecosystem processes, revealing which constellation(s) of species optimally contribute to critical conditions for the functioning of ecosystems and why. Examples are optimizing pollination and production factors, nutrient cycling and resistance to pests [43, 46]. Functional diversity is a way to allocate organisms to functional groups based on their functional traits. These are traits that make an organism compatible to contribute to a function under specific conditions. The concept of functional diversity is introduced in ecology sciences for a similar reason as why it is interesting for the goal of this research: *"Functional diversity generally involves understanding communities and ecosystems based on what organisms do, rather than on their evolutionary history"* [42]. This is in line with the goal of this paper; getting insight into what kind of functions actors perform in CBP, without the pre-assumption of their roles historically observed in projects.

Translation of functional diversity perspective to circular construction projects.

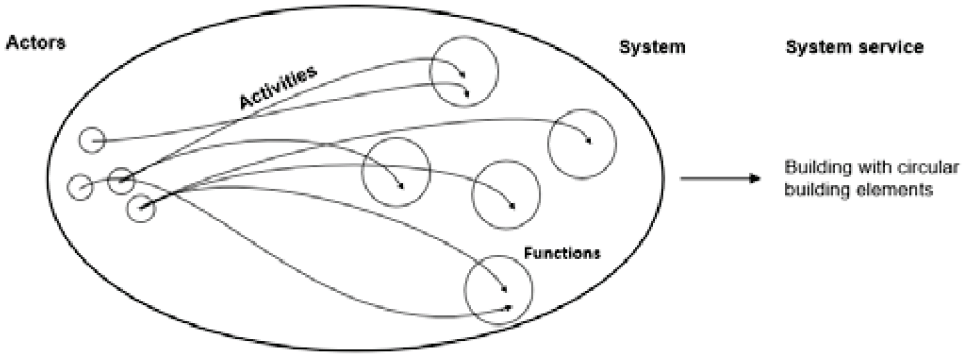

Figure 1: Functional diversity framework for circular building projects. Actors can be linked to one or multiple functions through their activities. The whole of actors and performed functions forms the system that produces the system service: circular buildings.

In this paragraph the FDP is translated to a CBP-compatible functional diversity perspective. This perspective departs from the starting point that a CBP can be seen as a system with a system services, which emerges through functions performed by actors through their activities, as depicted in figure 1.

Similar to a system of organisms, a system of actors can be structured in terms of functions performed. This means that a CBP can be mapped as a system of actors who each perform a function, from which a system service emerges, in this case a building with circular building elements. In this research a framework consisting of four elements is used (figure 1): system service, functions, actors and their activities. This framework is used as a basis for the analysis of cases studies, as described in the following chapters.

METHODOLOGY

We used case studies with a qualitative approach to find out what actors do in CBP. As Yin [47] points out, case study research is a linear but iterative process which enables the researcher to understand a specific phenomenon in all its complexity. Specifically, studying cases by applying the functional diversity framework also allows for cross-case comparison, making sense of similarities and differences, by looking through a conceptual equivalent lens [48]. Four cases were selected, each being completed CBP in the utility construction sector in the Netherlands: a thrift shop in Houten, the Alliander office in Duiven, the Haka building in Rotterdam and lastly the 8th floor of the 100 Watt tower in Amsterdam. The cases are representative for a large part of building projects in Europe, due to their small to medium size and a minimum of at least a commissioner, contractor and architect directly involved with the project. Table 1 provides an overview of the cases studied and their circular building elements.

Table 1: Circular results in the cases studied as system services

	Remanufacturing	Reuse/redistribute
Thrift store, Houten	Wooden façade covering from dismantled pallets	Concrete slabs as façade
HAKA building, Rotterdam	Partition walls from clothing, furniture out of remanufactured wood	-
Alliander office, Duiven	Wooden façade- coverings from dismantled pallets	Reused toilets and furniture
8th floor 100 Watt tower, Amsterdam	Partition walls harvested from a donor building	Reused carpet, reused furniture

Data collection

Data were collected through a total of 8 interviews (two actors interviewed per case) and an expert-panel to evaluate the results of the interviews. Interviews were conducted with actors who had a prominent role in the cases and who were involved in at least the initiation, design and construction phase of the project. The interviews were recorded and the recordings were stored. Photos of post it's used to make an inventory of the activities during the research were made in order to reproduce the data for the analysis. A summary of the interview was sent to the interviewees afterwards to confirm the results. In this research, actors can be interpreted mainly as a group of people affiliated with the case through the organization they work for. Project managers however are represented by one person in the cases, since this role is typically executed by one person. The system boundaries were maintained by identifying organizations that were directly involved in the project or because they represented a link in the supply chain of circular building elements. In order to structure the interviews, the backward analysis approach [49] was used. This approach is used in case studies to uncover sequences of cause and effect prior to a specific outcome of interest. This leads to the following interview structure.

1. *Introduction:* the interviewee was asked about his/her involvement with the project, the activities (s)he performed and when (s)he got involved.
2. *System services identification:* the interviewee was asked to summarize the circular building elements which were realized in the project. The elements were written on post-its.
3. *Actor-system identification:* the interviewee was asked to write down the name of each actor which (s)he regards to be crucial for the realization of the circular building element on a post-it. These post-it's with actors were placed next to the post-it's with the corresponding system service.
4. *Activities identification: u*nder each name that was written on a post-it in step 3, the interviewee was asked to indicate what made the actor crucial to the process. This could be anything, from a certain skill, action, to a specific technology (s)he used.

Data analysis

Specifically interesting in the data analysis of different cases, is that comparable behavior and patterns can be extracted, in turn enabling the identification of recurring case study mechanisms [50]. Following this approach, the data were analyzed through the following steps:

1. *Make an inventory*: list the system services for each case;
2. *Map actors and activities*: list actors and their activities related to a system service of each case separately;
3. *group activities from different cases in a cross case overview*: The activities observed in the different cases were matched through identification of the nature of the activity: what was the actor aiming to achieve?;
4. *Analyze groups*: in keywords, name the essence of each group of activities according to what these actors aim to achieve.
5. *Establish functional diversity*: list the keywords of each group in order to review the results. If necessary, optimize words in order to completely cover the observed activities.

In order to validate the results of the interviews, a panel with six practitioners in CBP was organized. In order to stimulate impartiality, the practitioners were not directly involved in the cases. To make sure enough expertise was present, the experts were required to have personal experience in CBP. The expert session was based on Quist's (2007) interactive back casting study method, step 1 to 3 specifically.

CIRCULAR BUILDING PROJECT CASES

This section presents and describes the four CBP cases. Each case is summarized, followed by an inventory of the actors and their activities that contributed to the system services apparent in the case and are shown in tables 2 – 5. The activities are listed in chronological order.

Thrift store, Houten

The municipality of Houten aimed to develop a new thrift store. Through a procurement process, in which "vision on sustainability" was one of the selection-criteria, the market was challenged. Engineering & consultancy bureau Arcadis won the tender, because they were considered to have a convincing vision on sustainability and the lowest price for the development of the building. Arcadis served as project manager, advisor and architect, responsible for cost calculation, quality and design. They formed a consortium with a combination of contractors van Bekkum and De Zeeuw. Table 2 provides the significant activities that contributed to the system service.

Table 2: Actors and activities collected in the interview during the Thrift store case study, resulting in the system service of reused wood for façade cladding

Actor	Activity
Municipality (Commissioner)	Setting "Vision on sustainability" as a selection-criterion for the procurement of the project.
Architect and project manager	Developing a convincing vision on sustainability, combined with a low price for the development of the building.
Architect, project manager and municipality	Looking for materials to reuse in the surroundings of the building site, through online search engines or by looking for other projects owned by the municipality from which materials can be reused. A company called 'Triade' was found through an online search, who offered used wooden boarding.
Triade	Collecting old wooden pallets, removing nails, storing them and putting them up for sale online as reusable wooden boards.
Architect	Consequentially to the decision to reuse the wood, the architect had to adjust the design of the façade based on the measurement of the used wood.
Municipality (as property manager) and project manager.	With the reuse of wood, chances are that some of the facade may require maintenance earlier compared to newly produced wooden boards. The project manager discussed this in an early stage with the municipality. Due to the ambitions of the municipality's aldermen and property manager that match the project managers vision, they accepted this as an investment that is worth realizing a circular facade.
Materials specialist	Reusing wood from pallets results in uncertainties regarding fire safety and being heavy rainfall-proof. A materials-specialist was involved, who could advise on quality standards concerning climate and safety. This gave the commissioner confidence in the circular facade.
Contractor	Mounting the used wood to the facade required many hours of labor. Finding people with a distance to the job market (thus a low hourly rate) for the preparation and mounting of the wood to the façade was necessary to avoid exceeding the budget.
Workers with a distance to the job market	Cutting wooden boards into correct size and mounting them to the façade under supervision of the contractor.

Alliander office, Duiven

Alliander, a Dutch gas and electricity infrastructure network operator, occupied an office in Duiven that was considered outdated. The organization needed an office that could accommodate its growth. For the redevelopment of their office, Alliander had put "quality of the vision" of the applicants as one of the central selection criteria in the procurement. applicants were not only selected on price and quality but were additionally asked to explain how they could contribute to reusing materials and other sustainable solutions in face to face interviews. The winning consortium was a team of architect RAU and contractor Boele & van Eesteren (amongst others). Table 3 lists the significant activities that contributed to the system service. Advisor Copper8 was responsible for the strategic commissioning of the project in collaboration with Alliander. For the further execution of the project, Alliander delivered a project manager from their own organization, who worked together with counterparts from the architect and contractor.

Table 3: Actors and activities collected in the interview during the Alliander office case study, leading to the system service of reused wood as a façade cladding.

Actor	Activity
Advisor and Commissioner	Setting 'quality of the vision' as an important selection criterion for the procurement.
Contractor and architect	Writing a winning vision on reusing materials, with the outstanding ambition that 80% of the used materials are to be reused.
Project manager	First step of the project manager was to generate as many ideas for reusing materials as possible. Workshops with Alliander employees generated ideas for materials to reuse. One idea was executed: reusing workers clothing as insulation material.
Project manager	From the workshop many ideas were collected, however only one was feasible which was not enough to meet the 80% reuse-ambition. The project manager had to look for more sources of reused material. A waste-processor that was located near the office was asked for an inventory of materials they obtain weekly. This uncovered that a substantial amount of wooden pallets passes through the waste processes that could be reused.
Architect	At the same time, the architect was performing studies on possible materials to reuse and how to apply them in a design
Contractor	A team of people with a distance to the job market (i.e. low hourly rate) was initiated to dismantle pallets for a lower hourly rate than the contractor could deliver with own personnel. Also, storing the pallets on the construction site turned out to be important.
Contractor and workers with a distance to the job market	The workers were cutting pallets into correct sizes applicable for façade covering, under supervision of someone from the contractor. Afterwards the contractor processed the used wood as façade cladding and mounted them to the building.
Project manager	It turned out to be crucial to involve the fire department early in the process to gain their willingness to collaborate on the project, instead of consulting them at the latest moment. It was foreseen that the contractor could not prove sufficient fire safety of the reused wood without a test.
Safety advisor	An advisor was hired that made mockups of the façade, set them on fire and concluded that the wood was safe to use.

HAKA building, Rotterdam

Real estate developer Vestia acquired the HAKA building in Rotterdam, to redevelop it into a mixed-function building. Their aim was to gain a prominent position as real estate developer in the area by renovating this monument into a sustainable icon. Because the HAKA building is a monument, reuse of materials was a central theme to the project from the beginning, in order to retain the heritage value. This resulted in the vision to also re-use as much materials as possible for new building elements that had to be added to the building. Table 4 presents the activities necessary for realizing the system service.

Table 4: Actors and activities collected in the interview during the HAKA building case study, leading to the system service of reused wood for a stage and reused clothing for a partition wall.

Actor	Activity
Project manager and architect	Setting the ambition of the building as an 'icon for sustainable development', by means of reusing materials found in the near vicinity of the building.
Architect	Searching for materials to reuse, the architect stumbled upon a nearby second-hand clothing collecting facility. A large pile of clothing disapproved for reuse was donated for use for the HAKA building.
Project manager	For applications such as a podium and partition walls, Vestia's project manager started contacting colleagues who were working on projects scattered around the city. This resulted in the harvest of reusable wood.
Waste processor	The two waste processors involved with the projects providing the wood, stored the materials temporarily on their terrain until the project manager organized transport of the materials to the HAKA building.

Project manager & specialist supervisor	Assembling the materials to produce the building elements designed by the architect proved to be too expensive if the work was done by the already hired contractor. The project manager found an organization which helps law-offenders with reintegration in society after their sentence has passed. A team was assembled to process the harvested materials into building elements. Intensive supervision was necessary to make sure the team could construct the building elements, for which a specialist construction supervisor was hired. Together they assembled several partition walls and a podium.
Architect	Designing a partition wall from reused clothing and wood and designing a podium from reused wood, including instruction manuals for the team of workers how to mount the building elements.
Project manager	Few weeks before date of completion, the interior elements were tested for fire safety. The fire department was very concerned about the partition wall's fire safety due to the use of clothing. The project manager ensured fire safety by hiring a specialist company, in order to impregnate the wall with a fire retardant. This cost extra time because the separation wall had to be dismantled in order to properly impregnate the material.

8th floor 100 watt tower, Amsterdam

Copper8 is a Dutch advisory company focusing on circular economy and sustainable development. As their organization grew, suitable office space was needed. They found a suitable office, however the floor they would occupy needed a retrofit. Copper8 decided that the retrofit should be in line with their ideas on circular economy. The significant activities in table 5 where found crucial to the realization of system services. Due to the fact that no structural adjustments to the building were made, no extensive fire-safety control was necessary.

Table 5: Actors and activities collected in the case during the 100Watt tower case study, leading to the system service of reused partition walls to divide the office floor into meeting rooms and working spaces.

Actor	Activity
Commissioner and project manager	The project manager of Copper8 had to convince the property owner of their circular vision. The property owner acts as commissioner since they are the ones investing in their own building by request of the new tenant. It took some effort but in the end the commissioner was convinced and adopted the vision and proposed business case.
Architect	The architect started looking for materials to reuse, mainly through online search engines. The biggest breakthrough in finding reusable material however was done by the intern of the architect who rode his bike through Amsterdam, visiting construction projects and looking for materials to reuse. A project where used glass partition walls were discarded was found.
Commissioner and waste processor	Searching for reusable materials from other buildings in property of the commissioner. Also, the commissioner made effort negotiating with the hired demolisher about the price for reuse, storage and delivery of the glass partition walls.
Contractor	A carpenter was hired as a contractor, who was able to make adjustments to the glass partition walls in order for them to be installed. Since it was a fairly small project, this one-person contractor could handle the project. His tariff is lower than that of hiring an organization which proved necessary to not exceed budget.

FUNCTIONAL DIVERSITY OF CIRCULAR PROJECTS

This section is the result of steps 3 to 5 of the data analysis (see Section 3) in order to distill generic functions performed in circular building processes. Activities were compared and coded according to similarities, resulting in groups of activities. For example; interviews brought forward activities such as "intern riding a bicycle through Amsterdam looking for materials", "Project manager searching for reusable wood through online search engines", "Architect visiting second hand clothing depot in the nearby harbor" and "Project manager contacting nearby waste processer inquiring for reusable material". The similarity is that in all these activities, actors were looking for ways to find a supply of circular material for the demand of the project. Thus, the function 'Matching supply and demand' was distilled.

In total, five functions were distilled that occurred in each of the cases. These functions appeared to be crucial to CBP: Connecting through vision, Matching supply and demand, Providing used materials, Constructing products and building elements and Controlling safety and quality. The functions are described below. We summarize the nature of the function, who performed the function, and the recognizable set of activities, followed by a cross-case overview of which actor performed which function.

Function 1: Connecting through vision

This function entails establishing a vision. Actors who are involved with creating the vision, believe in the vision and agree upon pursuing it. In each of the case, a shared vision set in the beginning of the project turned out to be crucial. An important moment to set a vision is when a consortium is formed that will design and build the project; this is the moment to collectively agree upon the ambition to adopt circular principles and to what extent. Also setting the rules of the game is an important activity (for example in the tender procedure) and setting a business case that involved parties could agree upon. Characteristics like enthusiasm, being highly driven, and being able to inspire people are important to perform these activities and thus the function. For example; the Vestia project manager who co-created the vision for reuse and sustainability for the HAKA building was a charismatic man who also repairs old cars as a hobby; this inspired others to realize a circular building.

Function 2: Matching supply and demand

The search for reusable materials that fit with the project-vision is recognizable in each case. Actors aim to expand the search for reusable materials geographically (e.g. visiting demolition projects in the vicinity) or within their own organizations by use of online search engines and workshops. This function is easier to perform by actors who own multiple properties, have access to online search engines and have the time and money to visit organizations that handle used materials such as waste processers.

Function 3: Providing used materials

Physically selecting, storing and moving used materials from A to B is necessary in order to construct circular buildings. This includes being able to separate usable materials from non-usable ones. Temporary storage space is necessary, since the moment of installing the materials in a building always differs from the moment the materials are harvested. When a waste processor is actively contracted on a project to demolish a building, persuasion was necessary in order to convince the waste processers to separate these materials from waste streams and store them onsite. This is due to the fact that part of their ‘business’ is being taken to reuse. In the cases where a waste processor is asked what materials they still have on their terrain, they proved to be cooperative since these are reusable materials but sometimes too specific in size or other characteristics, making the materials difficult to sell to most customers.

Function 4: Constructing products and building elements

This function entails the construction of usable products and building elements from used materials. Since the used products usually do not fit the design of the building, They have to be processed in order to apply them as building elements. In all cases studied, regular construction workers delivered by contractors where over-qualified (i.e. too costly) for this work. Thus, alternatives had to be found. In three of the four cases people with a distance to the job market were found. In the cases where people with a distance to the job market worked, supervision by an experienced person was necessary. Being creative in how to use unconventional products and remanufacture them into building elements is necessary. For example knowing how the old doors are used in partition walls in the HAKA building, or how the old window frames are reconstructed as partition walls in the 100Watt tower.

Function 5: Controlling safety and quality

Ensuring the quality and safety of buildings when materials are reused is dominantly present in CBP. It takes extra effort to ensure the quality and safety of used materials compared to the use of virgin materials. In the end, the authorities and the commissioner and/or property manager have to agree with the chosen materials and it’s specifications, for example requiring more maintenance than virgin materials require. In cases where this risk had been mitigated early, unforeseen situations later in the construction process are avoided. For example by involving the fire department in the design phase in the case of Alliander, fire safety was ensured during the process, contrary to the HAKA case where the fire department was involved in a later stage and ensuring fire safety put the planned delivery date of the building in danger. Table 6 presents a cross-case perspective to which actors contributed to what functions:

Table 6: Cross case overview of functions performed by which actors

Thrift store Houten	Alliander office, Duiven	Haka building, Rotterdam	8th Floor 100 Watt tower
Connecting through vision			
Architect Commissioner Contractor Project manager	Architect Commissioner Contractor Project manager	Architect Commissioner Municipality	Commissioner Project manager
Matching supply and demand			
Architect Commissioner Project manager	Architect Commissioner Project manager	Architect Commissioner Project manager	Commissioner Project manager
Providing used materials			
Contractor Waste processor	Contractor Employees Alliander Waste processor	Waste processor	Waste processor
Constructing products and building elements			
Contractor People with a distance to the job-market	Contractor People with a distance to the job-market	Supervisor (hired by project manager) People with a distance to the job-market	Contractor
Controlling safety and quality			
Project manager External advisor Municipality	Project manager External advisor Municipality	Project manager Municipality	Project manager

The following patters can be seen when looking at the cross-case functional perspective:

- In two cases, the contractor was involved with the function 'connecting through vision'. In these cases, the contractor also proved to pro-actively contribute to the function of 'matching supply and demand'. In the latter two cases, the contractor was not directly involved in creating a vision, which also proved to reduce contribution to the matching supply and demand function. This suggests that involving the contractor in this function can be helpful in finding materials to reuse.
- Involving authorities such as the municipality and fire department in an early stage, can drastically reduce costs and time spent on the process of 'ensuring safety and quality', in terms of not having to deal with unforeseen barriers in later stages of the construction process. In two cases this was apparent while one case brought forward a significant delay in the project due to not involving authorities in certain design choices.
- The commissioner of the projects is an important actor to the function 'matching supply & demand'. This is due to the fact that the commissioner is involved in establishing the vision to the project and because they are part of an organization owning real estate and thus potential resources.
- Labor costs proved to be decisive for the type of labor used for the circular building elements. Three out of four cases involved people with a distance to the job market. All cases brought forward that supervision is extremely important when working with groups like these.

DISCUSSION & LIMITATIONS

This research aims to provide insight into how actors achieve circular results in CBP, in spite of all the barriers that prevent a transition to a circular economy. We argue that the project-level and how actors achieve circular results is underexposed in research concerning the transition to a circular building and construction sector. Resulting in a lack of guidance for practitioners to increase circular results. Thus, novel perspectives to unravel the way these results are achieved in projects are paramount. The functional diversity concept serves as a way to unravel how actors achieve circular building results. Hereinafter we discuss the results of applying the functional diversity framework and its effectiveness to understand the matter.

Most importantly, the cases show a high degree of improvisation performed by actors to fulfill the functions. This can be interpreted as a positive signal to practitioners that circular results can be achieved, even in a linear construction sector with the transition far from being there. This improvisation is the result of the immature market for materials to reuse, which forces actors to improvise by searching the internet, organizations or the surroundings of a project to be able to 'match supply and demand'. Or hiring advisors to test refurbished building elements on fire safety. This improvisation can be straining: architects and project managers spend their evenings searching for materials online, or contractors tasked with sourcing alternative types of labor. The cases indicate that a strong vision with clear ambitions for the project established by at least an intrinsically motivated commissioner, architect and ideally also a contractor, fuels the effort to improvise and in the end succeed.

That being said, this study also alarmingly shows how far the construction sector is from being circular. The mentioned barriers negatively affect the CBP: To reach circular results, it requires the scarce intrinsic motivation and leadership of individuals to maneuver around obstacles, thus making painfully clear how fragile the circular practice currently is and that if this remains the norm, a transition in the Dutch construction sector will not take place. Until then, we advise practitioners to be conscious to the required functions for CBP and to be willing to accept that improvisation is needed to achieve results.

The question remains, does the FDP produce novel results? The importance of establishing a vision has been identified as key for sustainable transformation in previous studies [51, 52]. Leising et al. [16] also find this more specifically for CBP. However, with the functional diversity framework we were able to uncover also other key functions (such as controlling quality and safety and constructing circular building products and elements) and what traits made actors suitable to perform these functions. This shows that the FDP is a valuable addition to the conceptual toolbox of researchers and practitioners interested in steering towards circular building practices.

Limitations

To our knowledge, this is the first time the concept of functional diversity is translated and applied outside of ecological sciences. A limitation to our study is a lack of comparable studies to be able to reflect on the gathered data and outcomes. This is greatly needed to assess the true potential of the FDP: would a different perspective reveal a more representative constellation of actors? Second, a limitation is imposed though the choice of cases, which can be regarded as medium size and even small. Large scale projects, in their complexity, tend to rely more on standardised processes and norms, forming a different type of niche. One can question what functions would be uncovered in comparison to the cases in this research. Third, it would be interesting to apply the FDP to the same company, operating two different CBP. This would add insights by revealing what factors could be accounted to the specific actor involved, or the project setting in general. Finally, our starting point was to obtain qualitative results about what actors do in CBP, contrary to the mostly quantitative use of the functional diversity framework in ecology sciences, e.g. to establish richness, evenness and divergence [53]. In that sense, this research did not yet benefit from the full potential of the functional diversity framework. It would be interesting to greatly increase the number of projects viewed through the lens of functional diversity, in order to establish the diversity terms of evenness, divergence, etc., gaining a rich understanding of functional diversity at the construction sector level.

CONCLUSIONS

The aim of this paper was to gain understanding of what actors do to achieve results in CBP. The functional diversity perspective was developed to distill generic functions from four cases of CBP and to explore the use of such a novel perspective. Five functions were found that were dominantly present in each of the cases: Connecting through vision, Matching supply and demand, Providing used materials, Constructing products and building elements and Controlling safety and quality. We found that the functional diversity perspective, 1) allows researchers to reveal the essence of the contribution of different actors related to a system service (in this case circular building elements) and 2), configure new constellations of actors and their roles and a useful perspective to unravel the dynamics of circular economy in the construction sector. We thank the practitioners for participating in the interviews. This study is published after consent of the gathered data is given by the interviewed practitioners. We thank the experts who contributed to the expert panel. This research did not receive any specific grant.

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