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CASE STUDY

Sustainable environmental remediation: an application of the community capitals framework

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Abstract

Remediation options for a contaminated site are traditionally identified by taking into account a variety of factors including the type of contaminant, soil properties and geophysical characteristics of the site, and the impacts of the contamination on the environment and on human and non-human biota. Following the introduction of the Sustainable remediation paradigm, the inclusion of socio-economic realities into decision-making for contaminated site remediation is gaining traction. However, integrating social considerations is a complex process since it involves assessing and operationalizing non-tangible aspects and requires a holistic and situated assessment of local particularities through stakeholder participation. Currently, there is a need to develop approaches and tools able to address this complexity. The aim of this study is to test the applicability of the Community Capitals Framework (CCF) for the inclusion of social considerations into environmental remediation. Using a qualitative multi-method research design based on document analysis and semi-structured interviews, this study uses CCF to identify assets relevant to the remediation of a historical NORM (Naturally Occurring Radioactive Material) contamination of the Winterbeek river (Belgium). For this purpose, it develops a dedicated analysis method able to trace the complex relationships between assets, impacts and capitals. Results show that CCF can find useful application for the identification of community perspectives and resources that may be fruitfully mobilized for sustainable environmental remediation processes. The study also suggests a potential expansion of the theoretical formulation of CCF to include new types of relationships between impacts and assets.

Keywords Community assets · Community capitals framework · Environmental management · Radioactive and mixed contamination · Sustainable remediation

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1 Introduction

Contaminated sites are defined as areas where the presence of hazardous substances in the environment can entail potential threats to humans and/or ecosystems (EEA, 2021), while also potentially hindering economic development and diminishing the property value and attractiveness of nearby communities (Smollin & Lubitow, 2019). Contaminated sites are considered an issue due to the risks they entail to human health and the environment, but also the extensive resources required for their assessment and clean up. The recognition of the potential negative effects that site remediation may generate beyond the primary scope of addressing an environmental threat (Søndergaard et al., 2018), such as high societal costs or large environmental footprints (Anderson et al., 2018), has led to the introduction of sustainability principles to contaminated site management (Holland, 2011; Hou & Al-Tabbaa, 2014). In the last two decades, a progression from an exclusive focus on technical solutions towards broader approaches encompassing environmental, social, and economic criteria has taken place (Cappuyns, 2016; OECD & NEA, 2016). Sustainable Environmental Remediation (SER) is currently an important, though often voluntary, guiding principle for the management of sites contaminated from anthropogenic and natural sources (Bardos, 2014). The goal of SER is to protect human and environmental health and well-being, by minimizing negative externalities during and after the implementation of remediation, and by including considerations over the utilization of scarce resources (Gavrilescu et al., 2011). Several initiatives have been set up in this direction; among others, the UK's Sustainable Remediation Forum (SuRF-UK) (CL:AIRE, 2010), 'Green remediation' by the US Environmental Protection Agency (US EPA, 2008), the 'Sustainability Roadmap' of the Network for Industrially Contaminated Land in Europe (NICOLE, 2011) and the European Co-ordination Action for Demonstration of Efficient Soil and Groundwater Remediation (EURODEMO, 2010). Simultaneously, a variety of decision-support tools for sustainability assessment of remediation options have been developed, such as Golder Sustainability Evaluation Tool (GoldSET) (Golder Associates, 2009), Sustainable Choice of Remediation (SCORE) (Rosén et al., 2015), SiteWise sustainable environmental restoration tool (United States Navy et al., 2015), Sustainable Remediation Tool (SRT) (AFCEE, 2010).

Despite these efforts, there remains a lack of consensus on how social aspects could or should be assessed beyond 'public acceptance' considerations. This has resulted in an imbalanced emphasis on environmental and economic indicators within decision support tools (Huysegoms & Cappuyns, 2017). Numerous obstacles persist in the evaluation of social sustainability, which is defined as "specifying and managing both positive and negative impacts of systems, processes, organizations, and activities on people and social life" (Balaman, 2018, p. 86). In the context of site remediation, the social dimension of sustainability is often narrowly confined to health indicators or the post-remediation use of the site. Nonetheless, the concept of social sustainability extends far beyond mere parameters, encapsulating volatile and subjective elements like the local community's perception of the site, the visual repercussions of remediation efforts, and a multitude of cultural, ethical, and personal factors (Turcanu et al., 2022). Given the complex and multifaceted nature of social sustainability, there is a pressing need for context-sensitive approaches to its assessment, which should be validated through real case studies. Social sustainability cannot be adequately appraised through conventional measurement systems and quantitative indicators alone (Corder, 2015).

This study responds to the lack of empirical research on the inclusion of social dimensions into sustainable environmental remediation by assessing the applicability of an asset-based community development (ABCD) approach, specifically the Community Capitals Framework (CCF) (Flora & Flora, 2008), to a site affected by mixed contamination (radioactive material and metal(loid)s) in Belgium. Contamination at this site resulted from the NORM (Naturally Occurring Radioactive Material) industries, as described below. ABCD is a strategy to promote sustainable development by focusing on the strengths and resources of people and communities while meeting their needs (Fogarty et al., 2018). In this context, assets are understood as valuable or useful resources that individuals and groups can use to generate future benefits. The CCF employs the concept of capital to indicate the assets—i.e., the stock of each capital-that communities have at their disposal. By identifying and investing on available place-based assets, the problems that affect people and communities are met in the process of building long-term resilience (Flora & Bregendahl, 2012). Assessing how different forms of capitals interact is crucial to fostering positive feedback loops (spiraling-up) that enhance sustainability and growth (Gubbay & McKendry, 2022). Understanding the systematic interactions between the capitals also allows mitigating potential negative feedback loops (spiraling-down) to other capitals. In fact, sustainable development requires ongoing assessment and adjustment of investments in different forms of capital to maintain a dynamic equilibrium aligned with evolving community needs (Edwards et al., 2019; Fernando & Goreham, 2018; Gutierrez-Montes et al., 2009).

Within the field of environmental remediation, CCF has the potential to be employed from the outset of a remediation project, for the comprehensive assessment of assets available in a specific community (including those linked to social sustainability). By identifying what is present in the community, the available assets can be built upon and used to inform the remediation process, while weak areas (where assets are unavailable or degraded) will be taken into account in order to prevent adverse effects. In fact, evidence from other fields shows that CCF fosters resilient and sustainable responses to changes in natural and built environments (Kais & Islam, 2016; Thompson & Lopez Barrera, 2019). Thus far, however, there is no empirical, bottom-up research assessing the applicability of the CCF for site remediation projects.

CCF is based on seven capitals: environmental, social, cultural, human, financial, built and political (see Table 1).

Asset identification consists in creating an inventory of community capitals and their interlinkages (Kretzmann & McKnight, 2005) by assessing both tangible (physical) and intangible (non-physical) assets through stakeholder involvement (GCPH, 2012). CCF was applied in this study to identify *how community-specific assets are envisioned by different stakeholders and how these were taken into account in the project planning and decision-making for remediation*.

This research offers an interdisciplinary approach to the subject of site remediation, situated at the crossroads of environmental sciences, human ecology, and social sciences, encompassing insights from development studies as well. Our findings advance the understanding of remediation processes from a systems perspective and provide reflections on the methods for asset identification. Moreover, this research includes methodological reflections on how CCF can be employed to foster sustainable remediation. To the best of our knowledge, it is the first time that CCF is applied to the remediation of a NORM site.

Table 1 Description of capitals included in CCF (Flora, 2011)

Capitals (main codes)	Description	Categories of assets (sub-codes)
Natural capital	Stock of natural assets that provide ecosystem services to the communities located in their proximity	Agriculture and farming; air quality; fauna and flora; land and common property; landscape; soil and water; weather; geographical location
Cultural capital	The way "people know the world", which is acquired through socialization and familiarity with a given social context	Ceremonies, festivities and festivals; cultural and religious institutions; language; norms, beliefs and values; taboos; traditions and customs; habits
Human capital	Demographic and emotional assets possessed by individuals and groups	Anxiety and fears; aspiration and expectations; demographics; education; employment and social security; health, safety and nutrition; human rights; leisure and recreation; skills, knowledge and competencies
Social capital	Connections, networks and interpersonal relationships among people and organizations that allow them to reach collective objectives	Collective identity; community services; leadership; mutual trust; perceived wellbeing; sense of future; social networks; societal security; working together and cooperation
Political capital	Institutional domains where citizens can exercise their actualized or potential capacity to influence decisions	Engagement; laws and guidelines; power relations; representation; resource allocation
Financial capital	Monetary assets that provide purchasing power for people and businesses	Expenses; income, wages, salaries and pensions; industry and businesses; investments, funds, loans, savings, liabilities and subsidies; economic valuation of natural resources
Built (or infrastructural)	Equipment and facilities that support human activities	Communication infrastructure; industrial buildings (production and other facilities); residential areas; river infrastructures; sewer and water systems; technical equipment, machinery and other tools; transportation and road infrastructures; recreational infrastructures

2 Case study

2.1 Selection

Two main strategies for choosing a case study are random selection and information-oriented selection (Flyvbjerg, 2006). For this research, selection was information-oriented. Specifically, the Public Waste Agency of Flanders (OVAM) and the Federal Agency for Nuclear Control (FANC) were consulted. Among the potential sites, the Winterbeek site was chosen by applying the following criteria:

(1) type of contamination: presence of NORM contamination;
(2) state of remediation: by assuring that remediation activities were ongoing or completed, the research could identify whether and which community assets have been recognized/used in the remediation process;
(3) use of the area being remediated: due to the scope of this study, the proximity of residential or recreational areas was a prerequisite.

The choice of a NORM site is motivated by the fact that the remediation of these sites poses specific societal challenges, among others due to the differing perceptions of radiological risks between experts and affected communities, the limited stakeholder involvement observed in practice, and the limited understanding of remediation among the general public (Turcanu et al., 2022).

2.2 Study area description

The Winterbeek is a lowland river in Flanders, Belgium. Its valley extends for more than 32 km: having its source in Beverlo, it flows through the natural reserve area of the "Vallei van de Drie Beken" until Zichem, where it becomes a tributary of the Demer (Fig. 1). The meandering course of the Winterbeek has a significant role in flooding prevention during heavy rainfall periods. Due to the pollution history of the

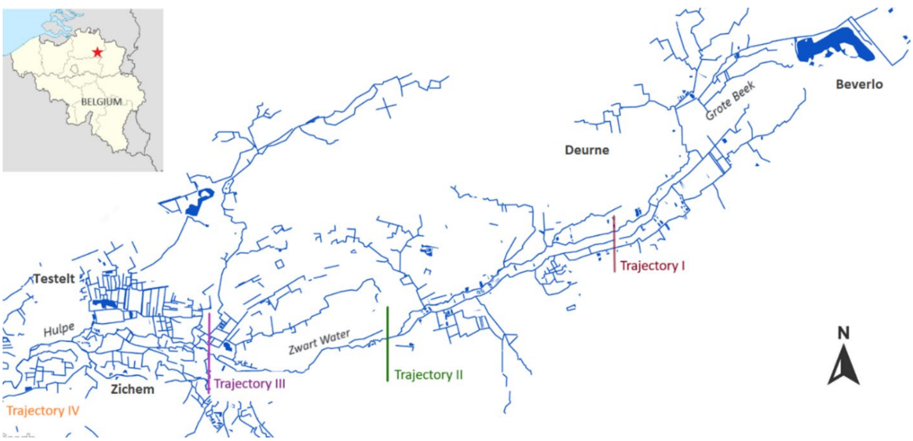

Fig. 1 The Winterbeek river and four trajectories of the remediation project

site (Cappuyns, 2023), metal(loid)s, extractable organic halogens and chlorides were present on the riverbanks and valley ground of the area, while elevated concentrations of radium were detected in the vicinity of the watercourse (OVAM, 2021). The cause of the contamination was the production of tricalcium phosphate (TCP) from sedimentary phosphate ore (FANC, 2014). Starting from the early 2000's, detailed characterizations of the spatial distribution of the contamination and its evolution over time were performed, in order to assess the risks of the contamination, as well as the need for remediation (FANC, 2023).

2.3 Environmental remediation

Based on the soil investigations, it was decided that a remediation was needed. In Flanders, remediation of contaminated soil must be done in accordance with the objectives of the Soil Decree, which includes the BATNEEC principle (Best Available Technology Not Entailing Excessive Costs) (VMM, 2007) for the selection of remediation techniques. Therefore, various preconditions were taken into account in decision-making, including the ecological importance of the area, the urgency of remediation, the time available for the remediation, the foreseen end use of the site, any planned redevelopment works and possible infrastructural restrictions, as well as financial considerations (Biermans, 2019). A series of remediation techniques were used in different areas, including soil/hotspot removal, immobilization, and monitoring (no intervention) (Boden, 2017). The soil remediation, which started in 2017, was implemented in four phases due to the extensive size of the project and its impact on financial budgets (OVAM, 2021). In each phase, remediation of a specific part of the river, referred to as "trajectory", was carried out from upstream to downstream, that is from the discharge point to the mouth of the Demer river (Fig. 1). Remediation works were completed in the first three trajectories in 2020, 2021 and 2022, respectively. Polluted riverbanks were excavated, and the contaminated material was stored on the industrial site of the TCP production plant (VMM, 2022). The remediation of the fourth trajectory of the Winterbeek started in September 2022. This area also includes the nature reserve of the Demerbroeken, which stretches until the point where the Hulpe flows into the Demer (Fig. 1).

Since the use of heavy machinery for the removal of contaminated sediment is not possible in the fourth trajectory due to the high natural value of the area, a nature-based approach is used, i.e. constructed wetlands (OVAM, 2021). This decreases the mobility and bioavailability of pollutants, thus avoiding the spread of the contamination and limiting the uptake by organisms (VITO, 2019). The remediation of this area falls into the scope of the LIFE NARMENA project (Nature-based Remediation of Metal pollutants in Nature Areas to increase water storage capacity), whose dual objective is to increase water storage capacity as a mitigation measure against increasing flood risks due to climate change while removing pollutants from contaminated watercourses (European Commission, 2021). The rewetting of the area is also carried out within the context of the Sigmaplan (https://www.sigmaplan.be/en/), a project established by the Flemish government to protect Flanders from flooding, and the Blue Deal, whose goal is to make Flanders resilient to water scarcity and drought (https://bluedeal.integraalwaterbeleid.be/about-blue-deal). The end use of the site after the remediation works will remain the same as before, namely a nature reserve.

3 Research material and methods

The objective of this study is to identify the seven capitals delineated by the CCF and examine their significance concerning the site remediation of the fourth trajectory of the Winterbeek. The aim is to assess the viability of the CCF as a comprehensive approach to sustainable environmental remediation, encompassing subjective and context-specific factors. The study employs a qualitative, multi-method research design, consisting in document analysis and semi-structured interviews with community members and technical experts. The latter indicates people involved in the decision-making and project planning of the remediation. The methodology chosen for the research is a case study, as this allows appraising theories and generating evidence through empirical observations that can be transferred to other systems (Gerring, 2004).

3.1 Data collection

3.1.1 Document analysis

Document analysis is often used, in combination with other research methods, for qualitative case studies (Stake, 1995). It consists of a review of documents, printed or electronic, to "elicit meaning, gain understanding, and develop empirical knowledge" (Bowen, 2009, p. 27). Furthermore, document analysis allows for the identification of insights on research context and data triangulation (Denzin, 1970). In addition to these reasons, document analysis is used in this study also to contextualize the data obtained from the interviews, track reported changes throughout the remediation project and identify relevant stakeholders. To conduct the document analysis, the three-step approach provided by Bowen (2009) was followed: superficial examination, reading and interpretation (p. 32).

3.1.1.1 Document search Documents were searched in (online) libraries, newspaper archives (Nexis Uni), citation databases (Web of Science, Scopus, Google Scholar) and Google Search. The online search was conducted in English and Dutch by using the following search string:

> *(Winterbeek or Hulpe or Demerbroeken) AND (remediation or pollution or vervuil* or saner* or gesanee* or besmet* or milieuverontreinig* or verontreining* or contaminat* or "zware metalen" or radioactiv* or radium or "Sigmaplan" or Narmena or "Blue Deal").*

Additionally, grey literature and policy documents were identified through consultation with technical experts (researchers' network) and made available from their organizational or institutional repositories.

In order to ensure that all the important sources were included, from the set of documents retrieved as described above, forward citation searching was used to identify additional relevant material until saturation was achieved. Documents referring to the whole remediation project or to the fourth trajectory of the remediation exclusively were included in the dataset; documents mentioning only the first, second or third trajectories and not dealing with the fourth one were excluded, as the focus area of the study was not included in these. In total, 64 documents (11 reports, 37 news articles 11 scientific articles, 3 webpages, and 2 conference presentations) were selected and an ID was assigned to each. The documents in Dutch were translated into English. The PDF versions of these were retrieved and imported to the qualitative analysis software NVivo (https://lumivero.com/products/nvivo/). The list of documents is reported in Appendix C.

3.1.2 Interviews

Semi-structured interviews were conducted following an interview protocol. Open-ended questions were used to facilitate the bottom-up identification of capitals and, with the latter, also to elicit associations between the identified capitals and sustainability dimensions of the site remediation. In total, 14 community members and 9 technical experts (Appendix E) were interviewed upon verbal or written agreement with the informed consent. Four invited technical experts (IE05) requested to conduct the interview simultaneously to guarantee representation of the three organizations they were affiliated with. This is the only group interview included in this study. None of the stakeholders representing industry accepted to participate in the interview. Interviews were conducted in English, in person or online via TEAMS, by the principal researcher. Each interview was recorded and transcribed. Transcriptions of the interviews were uploaded on NVivo for the data analysis.

3.1.2.1 Community characterization The study area was limited to the fourth trajectory (Fig. 1) of the remediation of the Winterbeek, where, at the time when the research was conducted, the remediation was still ongoing. Geographical boundaries were set for this research to align with the notion that a defined geographical area is pivotal in identifying a community (Bell & Newby, 1971). Moreover, establishing these boundaries was essential to ensure the feasibility of conducting the study within the timeframe and scope of the doctoral research project of the main researcher. However, this paper employs a definition of community that is not only locational (based on place), but also relational, i.e. based on a shared interest or issue (Bess et al., 2002). This definition of communities is in accordance with the guidelines provided by the International Atomic Energy Agency with regard to stakeholder involvement in environmental remediation projects, where communities are defined as people living on or using the land (IAEA, 2014). First, geographical boundaries of the fourth trajectory of the remediation of the Winterbeek were drawn with the help of official documents (OVAM, 2021). An exploratory search of the residential areas and facilities in the proximity of the fourth trajectory of the remediation was performed on Google Maps. The Ernest Claesstraat in Zichem, where an excavation zone was set in the proximity of the public road, was established as a starting point for the site visit (28.01.23). At the time of the visit and during the fieldwork, excavation works were ongoing (Appendix A). After the site visit, data aimed at identifying relational communities were gathered through an online search, a review of local newspapers, the establishment of a connection with local groups on social media platforms, and participation to other activities organized in the proximity of the area of interest during March and April 2023 (Appendix B). This information was later used in the study to recruit participants for the interviews (Sect. 3.2.) as well as to assign capitals to the community of belonging during the coding process (Table 2).

3.1.2.2 Ethical approval and recruitment of participants Ethical approval was granted, prior to the recruitment of participants. This study aimed to interview participants across different societal functions. Therefore, a purposeful sampling strategy was chosen (Patton, 1990). In addition, the sampling framework (Fig. 2) was developed based on current narratives in environmental policies inspired by the Quintuple Helix approach (Carayannis &

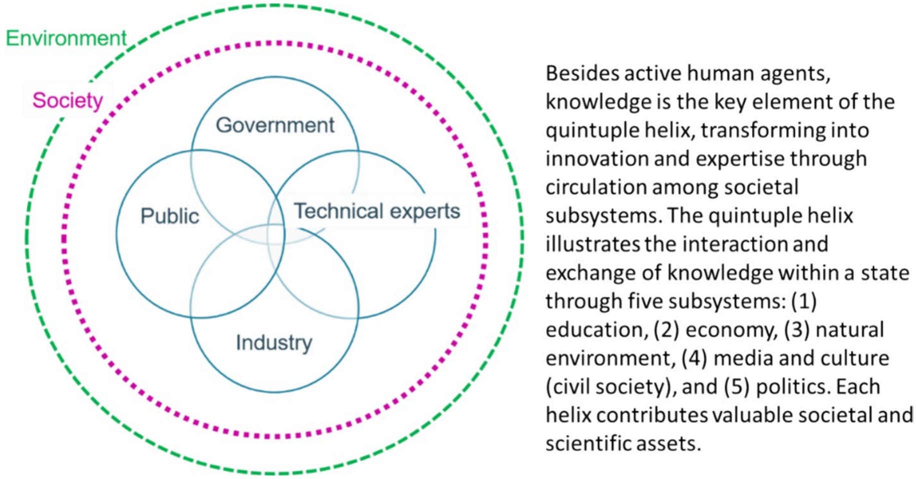

Fig. 2 Sampling framework. Adapted from Carayannis and Campbell (2010)

Table 2 List of communities which identified assets belong to. Each asset can belong to one or more communities

Community	Locational boundaries
European Union	Europe
National government	Belgium
Flemish government	Flanders
Industry	Whole course of the Winterbeek river
General public	Whole course of the Winterbeek river
RP (Radiation protection) experts	Whole course of the Winterbeek river
Local residents and land owners	4th trajectory of the Winterbeek river
Local government	4th trajectory of the Winterbeek river
Recreational users of the land	4th trajectory of the Winterbeek river
Non-human biota	Whole course of the Winterbeek and/or 4th trajectory

Campbell, 2010) and "mode 3" forms of knowledge production (Carayannis & Campbell, 2006). The Quintuple Helix Innovation System links the generation of knowledge through research and its implementation in innovation with the concept of "social ecology", which encompasses various societal factors and interactions (Carayannis et al., 2022). Environmental or ecological challenges can thus be leveraged as potential drivers for new knowledge production by encouraging learning processes between different stakeholders (Appendix E) (Carayannis et al., 2012).

The interviewed community members (public) were either residents living in or recreational users of the area located in the proximity of the fourth trajectory of the Winterbeek. Potential participants were recruited through the dissemination of a leaflet, which was distributed in person at local events and posted on social media platforms (Hoplr and Facebook) (Appendix D). No individual compensation was foreseen for participants, but a raffle was organized to foster participation. Technical experts, identified through researchers' networks and information available online, and representatives of government and industry, were sent an invitation letter by email.

3.2 Data analysis

3.2.1 Capitals, assets and communities

A systematic coding was developed through an iterative assessment, using as a starting point the capitals provided by the CCF and the categories of assets per each capital identified through a systematic literature review that preceded this study (Panzarella et al., 2023) (Table 1). Additional assets could be added to the coding if they did not fall under the scope of the existing categories and were identified throughout the coding process (emergent coding, Elliott, 2018; Stuckey, 2015). However, the a priori coding frame was sufficiently comprehensive to cover all assets encountered in the documents and the transcriptions of the interviews. The assets identified were classified under the seven capitals and their sub-codes (Table 1), and the communities of belonging (Table 2).

A positive sentiment (underlined in green color) was attributed to an asset if the asset was available at the beginning and/or during the remediation; a negative sentiment (underlined in red color) was attributed if the asset was unavailable or degraded at the beginning and/or during the remediation. As an example, in the section:

> *"Ernest Claes, the writer from Zichem, he wrote a lot in his books about how our nature used to be, but it was a long time ago. Many people now... They've got no idea about how the original sort of vegetation in the Demerbroeken used to be"* (IC04),

which was extracted from one interview, "*the original sort of vegetation in the Demerbroeken*" was coded as asset, natural capital (sub-codes: fauna and flora; landscape) and a negative sentiment was attributed to it, since the type of vegetation the interviewee is referring to was not available anymore at the time of the remediation.

3.2.2 Coding procedure

A manual coding of data retrieved from documents and interview transcripts was performed with NVivo. Only assets relevant for the remediation were included in the analysis, despite the sources often mentioned other assets as well (characteristics and details of the study area). For instance, the water infrastructure passing through the residential area of Zichem is an asset (built capital), but this was considered as not relevant for the remediation project.

A number was attributed to each asset preceded by the first letter of the capital the asset belongs to (B = Built; C = Cultural; H = Human; F = Financial; P = Political; S = Social; N = Natural) (see Appendix F and G). Several 'multifunctional' assets were found during the coding process, i.e. assets that can be categorized under two or more capitals. For example, the LIFE NARMENA project falls under financial (investments, funds, loans, savings, liabilities and subsidies), political (resource allocation; engagement), human (skills, knowledge and competencies) and social (working together and cooperation) capitals.

3.2.2.1 Inter coder reliability Since manual coding has been questioned for its reliability as conflicting codes might result from different coders (Hruschka et al., 2004; Olswang et al., 2006), an inter coder reliability (ICR) assessment was performed by the principal researcher and a second coder at the beginning of the coding procedure. This allowed to amend or add coding rules in case of divergent coding results. The second coder reviewed 15% of randomly selected documents. Between the two coders, there was an agreement of 96.69% with Cohen's kappa of 0.68, which indicates substantial agreement (Landis & Koch, 1977). While some argue that ICR is unsuitable and unnecessary for qualitative studies (Braun & Clarke, 2013; Guba & Lincoln, 1994; Hollway & Jefferson, 2013; Madill et al., 2000; Stenbacka, 2001), the ICR assessment was useful in this study to improve the consistency of the coding procedure as well as to promote reflexivity and discussion among the researchers, as already observed by others (O'Connor & Joffe, 2020).

3.2.2.2 Findings check Once the analysis was concluded, interviewees received by email a summary with the main research findings. In this occasion, they had the opportunity to review the work which had been done and comment on the findings.

4 Results

This paper focuses on the analysis of assets related to the remediation and the identification of spiraling- up and -down effects as a consequence of the interactions between assets. The information reported in this section relies on the tables included in Appendix F, Appendix G, Appendix H, Appendix I and Appendix J, but only the results that were found to be most notable are described in the text due to space limitations.

4.1 Asset identification

Both the document analysis and the interviews allowed identifying assets for each capital. However, apart from natural and human assets, substantial differences emerged when comparing the assets identified through the document analysis and the ones pointed out by community members through interviews.

4.1.1 Natural

Several community members interviewed were informed about the contamination from the phosphate industry and were aware that some environmental projects were ongoing (IC02, IC03, IC05, IC11, IC13, IC14). However, among these, only the volunteers of Natuurpunt—an independent volunteer association that ensures the protection of vulnerable and endangered nature in Flanders (https://www.natuurpunt.be/) knew that the objective of the ongoing works was the remediation of the site. Overlapping natural assets between document analysis and interviews concerned the high natural value of the area and its biodiversity, and climate related events (flooding and drought). Since the Sigmaplan, LIFE NARMENA and Blue Deal projects were implemented in parallel with the remediation of the Winterbeek river, assets related to the remediation partially overlapped with those related to the flood-prevention initiatives. Assets connected with the ongoing environmental projects, including remediation, were mostly associated to a positive sentiment. However, one community member (006) strongly opposed the creation of natural flood zones, claiming that they lead to ecological damage and will not be able to withstand future flood rates caused by climate change.

4.1.2 Human

Concerns, fears and anxiety on flooding in the area were common among stakeholders (003, 005, IC14, IC06, IE05, IE03). Knowledge, skills and competences in relation to the management of the area, including water management (003, 006, 101, 301, IE04). constitute the asset that contributes the most to the human capital. However, it was pointed out by community members (IC06) that disinformation about environmental matters is still widespread, and people should be better informed about ongoing initiatives, despite the presence of citizens' associations actively watching over that the industry's future plans will not generate additional environmental damage (018). The recreational usage of the land was also a widely recognized asset (201, 201, 501, IE06, IC03, IC08). Furthermore, multiple community members attributed value to nature for its contribution to people's wellbeing (IC03, IC06, IC10).

4.1.3 Cultural

Most cultural assets emerged from the interviews with community members. These provide a description of the social surrounding, such as language (IC03) and cultural and religious institutions—e.g., Ernest Claes, a popular novelist in Flanders, and the basilica of Scherpenheuvel-Zichem (IC02, IC04, IC08, IC11). Moreover, assets portraying norms, beliefs and values of community members were connected with environmental management principles (IC03, IC1, IC11). For example:

> *"I find it important that nature is not at my service" (that is, it is important to recognize the value of nature in itself beyond "cold" ecological considerations)* (IC03) and *"They are not very progressive in respect to ecology and the way they see nature" "(IC01).*

These observations do differ from the views encountered in document analysis and interviews with technical experts:

> *"An important condition here is that 'water as an organizing principle' is accepted. This means that the water system must (partly) determine spatial choices"* (323) and *"Not so formally, but always you try to use best practice: you try to use value for your money to be efficient, to be effective, but not really too much like sustainability goals at UN. UN sustainability goals are mostly for the water parts, the nature parts and less the social parts"* (IE03).

In fact, community members seem more attentive on the interactions between ecological and social systems.

4.1.4 Social

Working together and cooperation were frequently mentioned by different stakeholders (001, IC06, IE05). In the document analysis and interviews with technical experts, this asset denoted the joining efforts of all parties involved in the decision-making on the remediation (001, 003, 015, 201, IE01, IE05). Collaboration was facilitated by the fact that the polluter assumed responsibility for the storage of the contaminated material (IE05). In the interviews with community members, working together and cooperation were mostly mentioned in relation to the nature management activities organized by Natuurpunt (IC13, IC03) and people helping each other in case of flooding (IC06). Among the unavailable assets pointed out by community members, the lack of social interactions between residents of Zichem and newcomers (IC02, IC03), which were attracted to move there for the convenient geographical location and the attractive price of houses, was mentioned. Community members also pointed to lack of inclusion of individual perspectives into decision processes concerning the natural area in their surroundings (IC10, IC03). One interviewee mentioned the need *"to make place or give the opportunity to other forms of expressions"* (IC08), referring to his desire to expose his artwork to the community in the public space.

4.1.5 Financial

Available financial assets were the funds invested in the remediation and environmental projects (Sigmaplan, Blue Deal, LIFE NARMENA) (001, 003), which some of the community members were also aware of (IC02, IC14). In addition, 17 companies (other than the appointed main polluter) were mentioned as important sources of industrial discharges in the Winterbeek. This indicates the presence of business activities, which also provide employment for people in the area (023, 501). While their wastewater discharges contributed to the degradation of natural capital, the presence of such businesses was seen positively in terms of financial capital. Finally, the favorable housing market in Zichem was often mentioned by community members (IC01, IC02, IC09, IC10); *"The price of the house is much lower"* (IC09); *"Prices are reasonable here"* (IC10). However, it was not possible to establish, based on the available data, whether the market was affected by hedonic pricing effects—that is, the economic value of houses being lowered as a consequence of the degradation of environmental or ecosystem services due to the contamination in the vicinity of residential areas.

4.1.6 Built

The built capital, together with the natural capital, is where most of the identified assets belong. Available ones included, among other, the production process of the company responsible for the contamination and its new environmental permit allowing discharging chloride-rich wastewater into the Demer river (001, 303). The industry mainly responsible for the contamination also offered to use its site for the storage of contaminated sludge (001). Other available built assets were connected with the Demerbroeken nature reserve and include the presence of residential areas in its vicinity (006, 401), information boards (006), a visitor center (IC02) and observation platforms (IC03) for the recreational users of the area. River infrastructures, such as a holding basin (015) and an extra buffer zone (IC06), were coded as available assets. However, these were also associated with some criticism (006) as already mentioned in the section on *natural capital* above. Since the presence of busy road traffic in Zichem was frequently mentioned by community members (IC08, IC05), this was coded as unavailable asset, indicating a lack of transportation and road infrastructures, or a need for alternative roads, going around the village.

4.1.7 Political

Discrepancies between community members' and experts' perspectives clearly emerged from the analysis of political assets. Specifically for engagement and representation, experts claimed they made efforts in terms of stakeholder consultation and communication with rhe local public:

> *"We did the communication with the public and with other related stakeholders"* (IE01),
> *"Well, when the remediation plan was launched, everybody could speak out their concerns as just official procedure. When we launched the remediation plan, we made communication through local papers and the city hall, some websites... We also tried to media. So we have... We did reach out to the people"* (IE06),
> and *"Well, we also did stakeholder meetings. So meetings where everybody who has a stake in the area is involved and can express their concerns"* (IE06).

Conversely, community members expressed the desire to be better informed about the decision-making on the remediation and, more generally, the environmental management of the area, thus suggesting a lack of engagement and representation:

> *"In our opinion, these are matters that we and the local residents should know"* (014),
> *"So I think there is a lot of misinformation going on [...] and I think it's an assignment for, well, for the politics, for the people like the mayor and so on, to better inform people on that"* (IC03),
> *"I'm a bit lucky because they invited me to several meetings but otherwise all I would have known are the yellow papers of the community and the public letters of OVAM. That is all. It's because I'm a volunteer in Natuurpunt that I know a bit more and because I'm responsible for the cows and the horses in the Demerbroeken"* (IC13).

Other political assets related to available laws and guidelines that informed the remediation project (201, 301), such as the European Water Framework Directive and the Habitats Directive (001, 029, 319) and resource allocation from the Flemish government and the European Union (003, 005, 006, IC14, IC02).

4.2 Impacts of the remediation

To identify second layer attributes in asset identification, a code named 'impacts of the remediation' emerged to identify positive (highlighted in green color) and negative (highlighted in red color) effects of the remediation on the capitals (Fig. 3). For example, *"This rewetting of the Kloosterbeemden not only means added value for tackling the drought problem, it also ensures that pollutants no longer spread further and are less bio-available"* (321) denotes a positive effect of the remediation, and was thus coded as a positive sentiment. As another example, *"the work will be accompanied by noise and dust nuisance"* (014) describes a negative effect and was coded under impacts as a negative sentiment. Since noise and dust nuisance are only temporary impacts, the code "during" was created to distinguish the impacts of the remediation during remediation works from the longer-term impacts, that last even after the remediation works are completed.

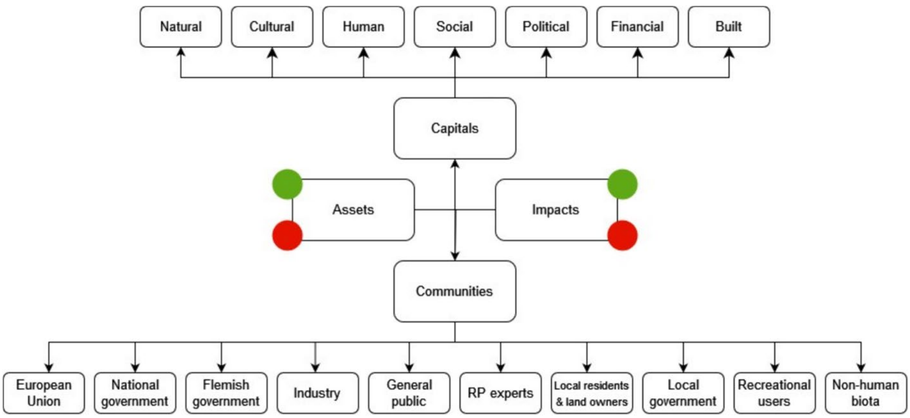

Fig. 3 Coding frame for data analysis

4.3 Spiraling-up and -down

Besides the identification of assets, and the positive and negative impacts, relationships were coded to identify the interactions between these assets and capitals and the impacts of remediation on each capital. In the theoretical formulation of CCF by Emery and Flora (2006), the spiraling-up is described as the positive effect that an investment on one capital may generate to other capitals. In the present paper, this process is referred to as 'asset building'. The expression 'to invest in a capital' or 'invested capital' is used when an existing capital is used as a leverage point to generate additional capital, i.e. asset building. The coding analysis, however, reveals that, in the context of a site remediation, positive impacts can also be generated through the remediation without investing in existing capitals. The expression 'asset creation' is therefore used to refer to the latter. *"Too much water… So, there is too much water in the villages, and it floods sometimes and this project aims to use this polluted area as a water retention area"* (IE06) is an example of asset building, as the presence of water is used in the context of the remediation to create a water retention area. On the contrary, *"The Flemish Region has decided to tackle the Winterbeek first next year in order to learn lessons from it for the Grote Laak"* (009) shows that, because of the remediation, new capital is created—in this case, human (asset: skills, knowledge and competencies)- without using existing assets as leverage points.

By taking the distinction between asset building and asset creation into consideration, four types of relationships were identified:

- positive effects of invested capitals on other capitals (asset building);
- positive effects of the remediation on capitals (asset creation);
- potential positive effects of non-invested capitals on other capitals (missed opportunities for asset building);
- negative effects of the remediation on available capitals (asset deterioration).

The first two relationships denote a spiraling-up process, while the last two relationships connote a spiraling-down process, thus suggesting that previously existing capitals were not used in, or deteriorated as a consequence of, remediation.

In order to track the spiraling-up and-down, a number was assigned to each type of relationship: 1 for asset building, 2 for asset creation, 3 for missed opportunities for asset building, 4 for asset deterioration (Appendix J/Impacted assets).

Most assets identified pertained to the built, political, human and financial capitals. Remediation generated predominantly positive, spiraling-up effects on built, human and political capitals (Fig. 4).

For what concerns the built capital, spiraling-up effects are generated because of:

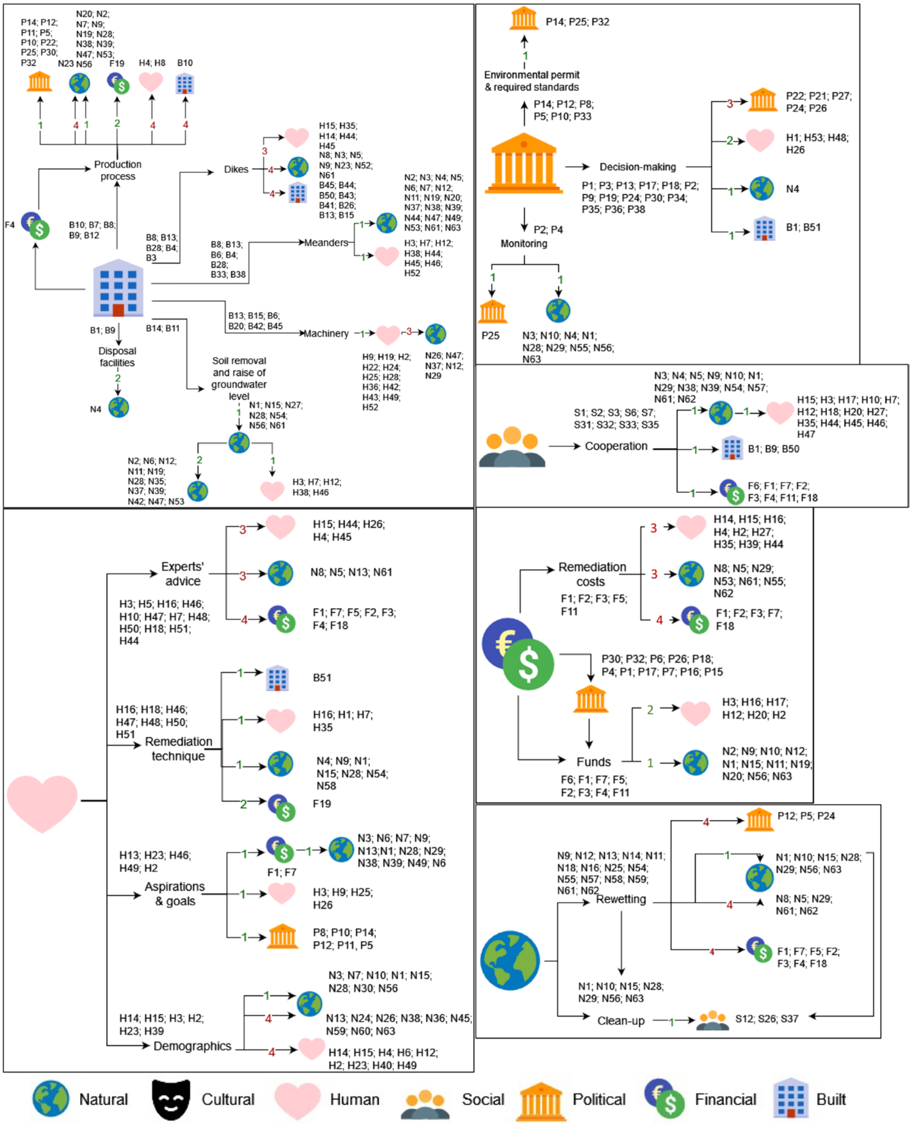

Fig. 4 Relationships between assets and impacts. From top to bottom, on the left side: built and human capitals; on the right side: political, social, financial and natural capital. Numbers indicate: 1 = asset building; 2 = asset creation; 3 = missed opportunities for asset building; 4 = asset deterioration

- *disposal facilities*: agreement between all the parties involved in the remediation on the use of existing sites for the storage of contaminated sludge;
- *soil removal and raise of groundwater level*, contributing to flood and drought prevention;
- *machinery*: intended here as both machineries to conduct remediation works as well as the tools used by radiation protection experts prior to the remediation (e.g. dosimetry assessment);
- *meanders*: they are useful for the storage of additional water, thus positively affecting biodiversity and diminishing the risks for residents connected with flooding.

Spiraling-down effects relate to:

- *dikes*: according to the expert's opinion in document 006, the dikes should not have been built around the natural area, but around the residential areas. This would contribute to better outcomes in case of flooding;
- the *production process*: the change in the production process of the industry responsible for the contamination is in accordance with the environmental permit and guarantees the continuation of business activities. However, this leads to salt discharge into the Demer river, reduction of workforce with natural layoffs, and decommissioning of installations for phosphate production process (in 2013).

For the political capital, the spiraling effects are all positive, except for the effect of decision-making (missed opportunities) on political capital. This spiraling-down effect relates to the lack of engagement and representation as expressed by some community members, who wished to be better informed regarding decisions on local matters. Apart from this, investments in political capital seemed to generate adequate support before, during and after the remediation, both in terms of available laws and guidelines and resource allocation.

In the case of human capital, spiraling-up is generated by the choice of remediation techniques and aspirations and goals of the parties involved. By working together, these were able to foster individual and collective goals in relation to the environmental management of the area (e.g., remediation of the site, re-naturalization of natural groundwater levels, protection against climate change). Spiraling-down is observed in relation to:

- *experts' advice*: despite the initiatives in environmental management, future flooding and salt discharges connected with the new production process mentioned above seemed to raise concerns among community members, also in relation to the perceived inefficient use of financial resources;
- *demographics*: remediation works partly affected nature management activities carried out by Natuurpunt. Furthermore, since the wetlands are anthropogenic, worries were raised in relation to the post-remediation management.

Mostly negative, spiraling-down, effects were identified in the case of financial capital. Spiraling-down for this capital was related to the ineffective use of resources to guarantee human and environmental safety. Furthermore, the decision-making of the remediation was described as taking into account remediation costs, but without including socio-economic considerations for the local residents—among others, the role of natural environment for perceived well-being, potential negative effects of recreational use of the nature reserve, limitations in nature management activities due to ongoing remediation works, high costs of post-remediation management, risks for human and non-human biota from future extreme climate-related events.

The largest number of assets identified pertained to the natural capital. However, this did not seem to affect the number of interactions with other assets, as the spiraling-up and -down effects were rather limited. Natural assets were invested for the site remediation and the creation of wetlands. Despite a distinction is made between these two goals in Fig. 4, they both contributed to the dual objective of the remediation and flood- and drought-prevention plan. Although some community members expressed the desire to receive more information about environmental decisions, site remediation led to positive social effects derived from the fruition of a clean environment for both residents and recreational users of the area. Spiraling-down effects on political, natural and financial capitals were connected, among others, to damages caused by the flooding (006) and use of resources for a project that does not offer a definitive solution since maintenance work and monitoring are required once the remediation is over.

Finally, investment in social capital manifested as cooperation efforts between different parties involved in site remediation. The partnership established with the main polluter for the storage of contaminated sludge was considered of particular importance, avoiding high costs of its disposal for the Flemish government. Spiraling-up effects on natural capital entailed the removal or rewetting of contaminated soil (in this way reducing the bioavailability of pollutants) and restoration of biodiversity; on built capital the availability of space that was freed up for new industrial buildings; and on financial capital the sharing of costs of the remediation between stakeholders.

No association was found between cultural assets and impacts of the remediation. Furthermore, none of the spiraling effects mentioned above seemed to have an impact on cultural capital.

5 Discussion

This study confirms observations made by others that "elements of the CCF need some modification as the process appears to have more complex relationships than proposed in prior research" (Pigg et al., 2020). In general, it can be stated that a broader view of the spiraling-up process than the one presented by Emery and Flora (2006), where the spiraling up is described as the positive effect that an investment on one capital may generate to other capitals, is needed. In the present paper, the process of spiraling-up is confirmed (cfr. 'Asset building (1)'). Three additional relationships are however identified through this research, i.e., 'asset creation' (2), 'missed opportunities for asset building' (3), and 'asset deterioration' (4). The first two relationships denote a spiraling up process or the creation, while the last two relationships connote a spiraling down-process, thus suggesting that previously existing capitals were not used in, or deteriorated as a consequence of, remediation.

By considering the observations above, relationships among community capitals could be used not only to identify gains and losses in the capitals, but also to:

- locate points of intervention where capitals can have a leverage function;
- assess a project and find opportunities for improvement through the identification of missed opportunities for asset building.

The empirical application of the CCF to site remediation in this study led to additional reflections on the causality between impacts and assets, and the opportunities for identifying assets to inform the post-remediation management of a site.

Furthermore, this study presents new prospects for the empirical implementation of the CCF. As previously observed, tracking the transformation of assets over time poses challenges, and evaluating the effects of a project on specific assets requires tracking them at multiple stages of the project (Panzarella et al., 2023). Our findings confirm that while identifying assets beforehand is crucial for informing the decision-making process, identifying them post-remediation completion can be relevant for project follow-up. For example, the availability of human capital for nature management activities was taken into account in the post-remediation maintenance of wetlands. Thus, recognizing an asset even after a remediation project is completed could be advantageous for achieving long-term site remediation objectives. In this manner, the CCF could serve as an iterative process, enabling the evaluation of available capitals for future use at any stage of a remediation project, including post-remediation.

This study shows that when faced with environmental challenges, local assets were strengthened to tackle the issue, and site remediation was utilized as an opportunity to bolster the area's resilience against additional environmental threats, such as flooding. Consequently, it was observed that, despite not formally recognizing certain assets, a site remediation project could still yield mostly positive impacts. However, assets not identified as such by remediation decision-makers could still be effectively utilized to mitigate adverse effects of the remediation and to optimize the use of local capitals. For instance, cultural capital could be leveraged by incorporating art installations to inform the local community about projects addressing environmental challenges in the area. Thus, this research underscores the potential for a more thorough analysis of site remediation by incorporating supplementary criteria, especially those pertaining to the unquantifiable social aspects of sustainability, through the application of CCF.

5.1 Ownership of assets

This study shows that communities, which the assets belong to, exceeded the boundaries of the remediation. For example, the allocation of European funds for flood- and drought-prevention measures influenced the site remediation project. In this case, funds came from outside of communities directly affected by the contamination and the site remediation works (residents, recreational users of the land). This expands the original definition of community capitals -where capitals relate to a community of place (Flora, 1998)— towards the application of the framework in a way that transcends locational boundaries. This is particularly relevant for sustainable site remediation, as remediation works might have far-reaching consequences on other communities—e.g., due to potential storage of contaminated sludge in sites other than the one affected by the contamination. A priori identification of assets that belong to both locational and relational communities could favorably contribute to holistically sustainable remediation strategies.

6 Conclusions, limitations and suggestions for future research

Recent years have witnessed a paradigm shift within the field of site remediation toward the inclusion of sustainability principles. This study investigated the potential application of CCF for a holistic assessment of sustainability in contaminated site management, with due attention to the social pillar. The framework itself incentivizes the employment of available assets to address local challenges in a way that stimulates positive development and resilience building. By applying it for the first time in the context of a site remediation project, this research shows that CCF may support the integration of stakeholders' perspectives into the decision-making and project planning (at different stages) of site remediation. Leveraging available assets and considering weak areas for intervention through a CCF-based approach can contribute to diminishing adverse effects while maximizing positive outcomes.

Findings from this study are confined to the fourth trajectory of the remediation project. Broadening the scope to include the other three trajectories could yield further understanding on the applicability of the CCF for sustainability assessment of the entire remediation project of the Winterbeek area. Moreover, the simultaneous implementation of various environmental projects (such as Life NARMENA, Sigmaplan, and Blue Deal) alongside the Winterbeek site remediation complicates establishing causal relationships between assets and impacts. These two limitations represent site-specific complexities. For this reason, comparison with other case studies will be beneficial for the evaluation of assets in relation to site remediation impacts, for the customization of CCF to site-specific contexts, and for methodological advancements in its application.

Ultimately, theoretical reflections on the underlying characteristics of CCF are necessary as the scope of its application expands to contexts characterized by complex system dynamics.

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Data availability Data will be made available on request.

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