The Traceability of Construction and Demolition Waste in Flanders via Blockchain Technology: A Match Made in Heaven?

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The traceability of construction and demolition waste in Flanders via blockchain technology: a match made in heaven?

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Abstract

The construction sector plays a crucial role in the transition to a circular economy and a more sustainable society. With this objective in mind, Flanders – the Dutch speaking part of Belgium – makes use of a traceability procedure for construction and demolition waste in order to guarantee that value can be derived from downstream waste processing activities. This article takes this traceability procedure as a legal case study and examines if the use of blockchain technology could lead to even stronger supply chains, better data management, and, more generally, a smoother transition to circular practices in the construction sector.

Keywords

Circular economy – Construction and demolition waste – Traceability – Blockchain – Data management – Supply chain management

1. Introduction

1. Many different countries and institutions are interested in leaving the polluting and unsustainable linear economy (take – make – waste) behind in favour of a circular economy.[3] Presently, the most 'popular'[4] definition of a circular economy is the definition coined by the Ellen Macarthur Foundation. According to the Foundation, a circular economy is "an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic

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[3] *European Commission (E.C.)*, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Closing the loop – An EU action plan for the Circular Economy, COM(2015) 614, p. 1, 2.; *Dutch Government*, Nederland Circulair in 2050. Rijksbreed programma Circulaire Economie, https://www.rijksoverheid.nl/documenten/rapporten/2016/09/14/bijlage-1-nederland-circulair-in-2050, 2016, p. 1, 17 (last consulted on 6 November 2020); *Flemish Government*, Visie 2050: Een langetermijnstrategie voor Vlaanderen, https://www.vlaanderen.be/publicaties/visie-2050-een-langetermijnstrategie-voor-vlaanderen, 2016, p. 1, 48 (last consulted on 6 November 2020).

[4] Not necessarily the best.

chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models."[5]

2. Belgium has shown great interest in the circular economy and has already taken several initiatives to boost this transition.[6] Especially Flanders (the Dutch speaking region) is very active within the scope of her competences (waste, urban planning, soil,…).[7] A prime example in this regard is the introduction of a traceability procedure for construction and demolition waste as well as the use of demolition management organisations. These organisations have, among others, the ability to certify the quality of selectively demolished and collected materials in order to process such waste stream in a more efficient and circular way.[8] The proactive role of Flanders – and Belgium as a whole – in waste processing is not surprising. After all, it is a region without a significant amount of own resources or raw materials, which is why it has to rely heavily on import.[9] On the other hand, the presence of an enormous amount of secondary materials in the (outdated) building patrimony and the strategic position of Belgium in Europe provide, among other things, strong incentives to take action.[10]

3. This article uses the existing body of literature[11] as a stepping stone to examine whether blockchains could enhance waste management processes in view of truly 'closing the loop' in the construction sector.[12] SHOJAEI *et al*. conducted noteworthy research on the use of blockchain

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[5] *Ellen Macarthur Foundation (EMF),* Towards the circular economy: Economic and business rationale for an accelerated transition, www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf, 2013, p. 1, 7. In 2017 Kirchherr, Reike and Hekkert tried to develop their own definition of a circular economy: *J. Kirchherr, D. Reike & M. Hekkert*, Conceptualizing the circular economy: An analysis of 114 definitions, Resources, Conservation & Recycling 2017 (127), p. 221, 224-225.

[6] For further information: *Flemish Government*, Coalition agreement 2019-2024, www.vlaanderen.be/publicaties/regeerakkoord-van-de-vlaamse-regering-2019-2024, p. 1, 204-205 (last consulted on 6 July 2020); *Belgian Government,* België als voortrekker van de circulaire economie, www.health.belgium.be/sites/default/files/uploads/fields/fpshealth_theme_file/belgie_als_voortrekker_van_de_circulaire_economie.pdf, 2014 (last consulted on 24 October 2020); *EEA*, Resource efficiency and circular economy in Europe – even more from less. An overview of policies, approaches and targets of Belgium in 2018, www.eionet.europa.eu/etcs/etc-wmge/products/b-country-profile-belgium_finalised.pdf, 2019, p. 1, 6-25 (last consulted 6 November 2020).

[7] Article 6 Federal special act of 8 August 1980 on the reform of the institutions, *Belgian Official Gazette* 15 August 1980, 9.434. *C. Behrendt & M. Vrancken*, Beginselen van het Belgisch staatsrecht, 2020, pp. 454-455.

[8] At the time of writing, there is only one recognised demolition management organisation in Flanders Ministerial Decision: MD of 24 August 2017 on the recognition of Tracimat as a demolition management organisation, *Belgian Official Gazette* 29 September 2017, 89.389. Website Tracimat: www.tracimat.be/.

[9] *EEA*, Resource efficiency and circular economy in Europe – even more from less. An overview of policies, approaches and targets of Belgium in 2018, www.eionet.europa.eu/etcs/etc-wmge/products/b-country-profile-belgium_finalised.pdf, 2019, p. 1, 6 (last consulted on 6 July 2020).

[10] *Belgian Government*, België als voortrekker van de circulaire economie, https://www.health.belgium.be/sites/default/files/uploads/fields/fpshealth_theme_file/belgie_als_voortrekker_van_de_circulaire_economie.pdf, 2014, p. 1, 16 (last consulted on 6 July 2020).

[11] E.g.: *G. Shemov, B. Garcia de Soto, H. Aklhzaimi*, Blockchain applied to the construction supply chain: A case study with threat model, Frontiers of Engineering Management, 2020 (7), p. 564, 564-577.

[12] *Perera* et. al. already briefly mention that blockchain could lead to better waste management: *S. Perera, S. Nanayakkara, M.N.N. Rodrigo, S. Senaratne, R. Weinand,* Blockchain technology: Is it hype or real in the construction industry?, Journal of Industrial Information Integration, 2020, p. 17.

technology in construction practices. Their hypothesis was that a blockchain platform can provide comprehensive, transparent, and reliable information to track and trace materials' source as well as the materials' current state.[13] SHOJAEI *et al.* distilled a sequence comprising of nine steps, with the salvaging of the building being the last stage. By relying on a blockchain, it becomes possible to not only preplan the salvage process, but also to record the reuse purposes of these salvaged materials. In turn, this could also aid the community at large to better comprehend the total value gained from a certain material or product.[14]

However, the salvaging and preplanned demolition which SHOJAEI *et al.* refer to do not guarantee the adequate execution of the demolition activities and, ultimately, the quality of the demolition materials. In an effort to pursue a more circular business model, it is of utmost importance that one can ensure the diligent performance of the demolition activities by verifying the data taken up in the blockchain. Moreover, it is also crucial that the blockchain can attest to the quality of demolished materials in order to genuinely 'close the loop'.

The Flemish traceability procedure can help with these aspirations. It provides the necessary guidance and foundations to leverage construction supply chains beyond the construction of a particular building. Moreover, a blockchain-based information system could supplement this traceability procedure and facilitate further streamlining. The availability of very precise data about a building which needs to be demolished will render the drafting procedure of a pre-demolition inventory (*infra*) easier and less time consuming. Scholarship confirms the view that blockchain-based supply chain management (i) improves the authenticity and regulatory compliance of (intermediary) products, (ii) leads to greater quality assurances vis-à-vis the final product, and (iii) ensures that an immutable record of the construction project can be retrieved at any time during the project's life cycle, even well beyond the post-construction stage.[15]

In spite of the value added by blockchains, the underlying technology cannot solve all the issues pertaining to the transition to a circular economy in the construction sector.[16] Therefore, the

[13] *A. Shojaei, R. Ketabi, M. Razkenari, H. Hakim, J. Wang,* Enabling a circular economy in the built environment sector through blockchain technology, Journal of Cleaner Production, 2021 (294), 2 (https://doi.org/10.1016/j.jclepro.2021.126352).
[14] *Id*. at p. 6.
[15] *S. Perera, S. Nanayakkara, M.N.N. Rodrigo, S. Senaratne, R. Weinand,* Blockchain technology: Is it hype or real in the construction industry?, Journal of Industrial Information Integration, 2020 (17), 16.
[16] For example, blockchain will in itself have no impact on CO_2-emissions or the quality of recycled or reused materials.

contribution's focal point lies on the lack of adequate information and data management.[17] In this regard, blockchains are believed to have good potential to lead to more trust and cooperation throughout the supply chain by means of better information processing, data availability, and sensibilisation.[18] Improvements in these areas can, in turn, aid the transition to a circular economy where the value of products, materials, and resources is kept in the economy for as long as possible while the generation of waste is minimised.[19]

4. The remainder of this paper is divided into four sections. Firstly, the Flemish traceability procedure for construction and demolition waste will be examined in detail (Section 2). Secondly, blockchain technology and its basic principles will be explained (Section 3). Thirdly, a discussion will follow on the benefits and shortcomings of combining construction and demolition waste management with the principles of blockchains in view of ensuring the adequate administration of data streams (Section 4). Fourthly and lastly, some concluding thoughts and possible ideas for further research will be put forward (Section 5).

2. Traceability of waste streams in Flanders

5. When a building in Flanders needs to be demolished, it is important to not just go about it but to aim as much as possible for a selective demolition and waste collection. After all, the use of selective demolition and separate waste collection practices could lead to more materials being available for reuse and recycling.[20] Such an approach is also in line with the goals of the Flemish waste legislation as set out in article 4 of the Flemish Decree of 23 December 2011 on the sustainable management of material cycles and waste (hereafter: the Materials Decree).[21]

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[17] *BAMB*, Framework for policies, regulations and standards, https://www.bamb2020.eu/wp-content/uploads/2019/01/BAMB-Framework-for-Policies-Regulations-and-Standards_with-Appendices.pdf, 2018, p. 1, 43; *EEA*, Circular Economy in Europe. Developing the knowledge base, 2016, nr. 2/2016, pp. 14 & 22 and following.

[18] Although it doesn't explicitely mention blockchain, the (draft) policy program of the Flemish public waste agency defines digital management of construction and demolition waste and a digital exchange of information as two important action points: *OVAM* , Op weg naar circulair bouwen, 2021, preliminary working paper, p. 29.

[19] *European Commission (E.C.)*, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Closing the loop – An EU action plan for the Circular Economy, COM(2015) 614, p. 1, 2. The possible link between blockchain and connection the supply chain in a circular economy was already discussed (and confirmed) in: *R. Casado-Vara, J. Prieto, F. De La Prieta, J. M. Corchado,* How blockchain improves the supply chain: case study alimentary supply chain, Procedia Computer Science 2018 (134), p. 396; *M. Kouhizadeh, Q. Zhu, J.Sarkis,* Blockchain and the circular economy: potential tensions and critical reflections from practice, Production Planning & Control 2019, 10 (https://doi.org/10.1080/09537287.2019.1695925).

[20] Also mentioned in: Annex MD 2 September 2019, p. 1; *B. Vandromme*, Asbest. Niet wachten tot het stof gaat liggen, 2019, p. 142.

[21] *Belgian Official Gazette* 28 February 2012, 12.943.

2.1. Pre-demolition inventory

6. A first step in the (selective) demolition process in Flanders consists of drawing up a pre-demolition inventory. This inventory includes an identification of the demolition site and an overview of the waste streams that are likely to be present on the site.[22] It also needs to contain certain data for each particular waste stream, for example the EURAL-code, the place of a particular substance in the construction, etc.[23] These pre-demolition inventories are drafted in accordance with a standard procedure imposed by the Minister.[24] Using a pre-demolition inventory is not compulsory for every demolition site though. Article 4.3.3., §1 of the Flemish Order of 17 February 2012 gives a list of projects for which a pre-demolition inventory is required. Accordingly, the inventory is obligatory for larger residential and non-residential projects and certain projects on infrastructure.[25] As expected, the burden of obtaining a pre-demolition inventory falls on the applicant of the integrated environmental permit.[26]

7. Once the pre-demolition inventory has been completed, actors involved in the demolition process can follow the traceability procedure through a demolition management organisation (DMO).[27] It is impossible to make use of this procedure without a pre-demolition inventory but there is, on the other hand, also no obligation to make use of the traceability procedure.[28] The parties could also decide to voluntarily make use of the services of a DMO for demolition activities for which a pre-demolition inventory is not required if they voluntarily choose to come up with a pre-demolition inventory.[29] Three types of traceability procedures exist.[30] For the purposes of this article, we will solely focus on the standard traceability

[22] Article 4.3.3., §2 Order of 17 February 2012 of the Government of Flanders adopting the Flemish regulation on the sustainable management of material cycles and waste (hereafter: the Flemish Order of 17 February 2012).
[23] *Id.*
[24] Ministerial Decision: Ministerial Decision of 2 September 2019 concerning the modification of the Annex to the Ministerial Decision of 3 February 2017 on the establishment of a procedure concerning the draft of a pre-demolition inventory and control report in execution of article 4.3.5., §3 of the Flemish Order of 17 February 2012, *Belgian Official Gazette* 10 October 2019, 93.349.
[25] *B. Vandromme*, Asbest. Niet wachten tot het stof gaat liggen, 2019, pp. 88-89 who mentions that these thresholds are too high and are a missed opportunity for a (needed) broader application of the pre-demolition inventory.
[26] Article 4.3.3., §1 the Flemish Order of 17 February 2012.
[27] The traceability procedure is not yet fully operational: Chapter VII Annex MD 2 September 2019. The duration of the last transitional provision was extended until 31 December 2021.
[28] *B. Vandromme*, Asbest. Niet wachten tot het stof gaat liggen, 2019, p. 145. He mentions that it should be obligatory for every demolition activity to draft a pre-demolition inventory. In a new legislative proposal, the Flemish government wants to make the use of the traceability procedure obligatory if it is required to come up with a pre-demolition inventory. For further information (and the proposal): https://www.ovam.be/vlarema-8-verplichte-sloopopvolging-met-traceersysteem-om-puin-beter-te-recycleren.
[29] *J. Voorter*, Vlaamse regelgeving zet nieuwe stap in de richting van een circulaire economie, de Juristenkrant 2019 (399), p. 1, 4. Also: *OVAM*, Asbest en sloop, https://www.ovam.be/asbest-en-sloop (last consulted on 26 May 2020). In that case a 'simplified' traceability procedure applies: Annex MD 2 September 2019, p. 7 and following. However, this possibility is purely hypothetical nowadays since no demolition company will voluntarily spend money to slow the demolition process down, unless the client explicitly asks for it.
[30] Annex MD 2 September 2019, p. 1.

procedure that applies to the demolition, renovation, or dismantling of all buildings with a volume that exceeds 1000 m³.[31]

2.2. The traceability procedure

8. The transfer of the pre-demolition inventory to the DMO is the first step in the traceability procedure. The DMO then has 30 working days to decide on the conformity of this pre-demolition inventory with the standard procedure, as mentioned in the Annex of the Ministerial Decision of 2 September 2019 on the procedure concerning the draft of a pre-demolition inventory. It will, among other things, look at (i) the completeness of the administrative documents, (ii) the appraisal concerning the presence of asbestos, (iii) the monitoring of the inventory of dangerous and non-dangerous waste, etc.[32] An advice on the reuse and processing possibilities of the construction and demolition materials can be included.[33] When the pre-demolition inventory does not meet the necessary requirements, the DMO will decide (i) that the inventory is incomplete, (ii) that further clarifications are required, or (iii) that the submitted pre-demolition inventory does not conform to the applicable requirements.[34]

9. Once the pre-demolition inventory has obtained a declaration of conformity from the DMO, the next step consists of the notification of the start of the demolition activities. When dangerous substances are present on the demolition site, the start of those specific activities should also be explicitly mentioned in the notification to the DMO. This notification should be given at least 24 hours before the start of the (general) demolition activities. Apart from notifying the start of the demolition activities, the demolition company also needs to inform the DMO about the expert who will be responsible for performing the control visit and for drafting a (preliminary) control report. If there is asbestos present, a control visit and report are always mandatory. For other dangerous substances, this is not always the case.[35] The control visit takes place during or after the removal of the dangerous substances. After the control visit, the expert makes a (preliminary) control report based on the earlier control visit and gives a – possibly

[31] Annex MD 2 September 2019, p. 2.
[32] Annex MD 2 September 2019, p. 2.
[33] Article 4.3.5., §3, 3rd section, 2° the Flemish Order of 17 February 2012. Some examples: which ‘disturbing substances’ should be monitored closely or which actions can be considered when dismantling, (selectively) demolishing a construction in order to facilitate reuse (Annex MD 2 September 2019, 2 -3). ‘disturbing substances’ are non-dangerous waste that may hinder the processing of selectively collected demolition material (Annex MD 2 September 2019, 2).
[34] Annex MD 2 September 2019, p. 3.
[35] Annex MD 2 September 2019, p. 3.

positive – advice.[36] The DMO has 10 working days to take a decision concerning the completeness and conformity of the control report.[37] If it takes a positive decision, it becomes possible to request a processing authorisation.

10. Article 4.3.5., §1 of the Flemish Order of 17 February 2012 dictates when a DMO can grant a processing authorization. Pursuant to this provision, the stony fraction needs (i) to originate from activities as mentioned in article 4.3.3., §1 of the Flemish Order of 17 February 2012,[38] (ii) to be collected selectively in execution of a pre-demolition inventory, and (iii) to be transferred to a site for the production of aggregates in accordance with the applicable regulations.[39] The demolition company needs to obtain such a processing authorization before it can transfer the construction and demolition waste for further processing. The DMO will accept or deny the request for a processing authorization within 5 working days.[40] With the processing authorization, the demolition waste (i.e. stony fraction) can be delivered to the intended recipient, who should be able to accept these materials under a LERP-qualification (low environmental risk profile).[41] If the traceability system was not used, there is less certainty about the quality of the materials, which implies that the materials can only be accepted under a HERP-qualification (high environmental risk profile).[42] HERP-materials can only be processed in a more expensive way.[43]

Some other important documents are worth mentioning as well. First of all, a transport document needs to be drawn up when the batch of materials is transferred for further processing.[44] The recipient of the demolition materials also needs to inform the demolition company and the DMO about the fact that he/she has received the materials with an

[36] Annex MD 2 September 2019, p. 3.
[37] *Id.*
[38] These are the activities for which a pre-demolition inventory is mandatory.
[39] Ministerial Decision: Ministerial decision of 25 July 2011 on the approval of a Common Regulation for Recycled Aggregates(‘Eenheidsreglement’), *Belgian Official Gazette* 23 August 2011, 48.351. The conditions in article 4.3.5., §1, third section the Flemish Order of 17 February 2012 to hand out authorizations for non-stony waste streams are less delineated.
[40] Annex MD 2 September 2019, p. 4.
[41] *Id.* at p. 5. The distinction between LERP and HERP is applicable since 24 August 2018 (one year after the appointment of Tracimat as the first demolition management organisation) and has/had as a purpose to introduce a substantial price difference in the acceptance of HERP material streams compared to LERP materials streams. This price difference should make it (financially) interesting to follow the traceability procedure of a DMO. See: Annex to the Ministerial Decision of 24 August 2017 on the modification of the Annex to the Ministerial Decision of 25 July 2011 on the approval of a Common Regulation for Recycled Aggregates, *Belgian Official Gazette* 29 September 2017, 89.389. Also worth mentioning: *OVAM*, Een beheersysteem en eenheidsreglement voor gerecycleerde granulaten, https://www.ovam.be/gerecycleerdegranulaten (last consulted on 26 May 2020).
[42] *B. Vandromme*, Asbest. Niet wachten tot het stof gaat liggen, 2019, p. 146.
[43] At least, in theory. Nowadays, most recipients of the demolition materials use the same prices for materials with a low and a high environmental risk profile which leads to a total lack of incentive to use the traceability system and bear the additional costs/time.
[44] Annex MD 2 September 2019, p. 5.

acknowledgement of receipt.[45] Apart from the recipient, the demolition company must also notify the DMO about the finalisation of the demolition activities.[46] Lastly, when applicable, the selected expert[47] needs to draft his final control report.[48] The required content and formalities for this control report can be found in the Annex to the Ministerial Decision of 2 September 2019 on the procedure concerning the draft of a pre-demolition inventory.

11. When the control report (if applicable) is approved and the other abovementioned elements are fulfilled, it is possible for the executor of the demolition activities to demand a certificate of demolition ('sloopattest').[49] The certificate confirms the selective collection of the demolition materials as well as the traceability of the stony materials from their origin to their controlled processing.[50] The certificate of demolition needs to be requested within 30 calendar days after the finalisation and acceptance of the demolition activities.[51] The DMO can decide to deliver the certificate, ask for additional information, or refuse to deliver the certificate. There is a special regulation for the stony fraction of demolition materials if this fraction is offered to and accepted by a processor for the production of recycled aggregates in conformity with the Common Regulation for Recycled Aggregates[52] ('Eenheidsreglement').[53] The certificate of demolition, if granted, contains at least some information on the nature of the selectively collected demolition materials, the quality of the selectively collected demolition materials with a statement on the presence of dangerous and/or disturbing substances and the quantity of the selectively collected demolition materials.[54] The DMO still has the possibility to request further information or to decline the request – in a motivated way – for a certificate of demolition altogether.[55]

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[45] Annex MD 2 September 2019, p. 6. There are a few additional elements that need to be mentioned by the recipient of stony materials, e.g. if the amount of selectively demolished and collected demolition waste that the recipient refused at the gate.
[46] This obligation is not mentioned in Annex MD 2 September 2019. It seems to be an extra step that was added by Tracimat as part of her traceability procedure: *Tracimat*, Schema traceerbaarheid Tracimat vzw, http://tracimat.be/wp-content/uploads/2019/08/schema-traceerbaarheid-met-uitleg_v20190819.pdf, 1-2. (last consulted on 26 June 2020).
[47] See above at no. 11.
[48] This is only necessary if the expert needed to conduct a control visit and make a preliminary control report. There is also a provision on unforeseen circumstances: Annex MD 2 September 2019, p. 5.
[49] Article 4.3.5., §2, first section the Flemish Order of 17 February 2012. This article also gives the opportunity to distribute certificates of demolition for non-stony demolition materials.
[50] Article 4.3.5., §3, first section the Flemish Order of 17 February 2012.
[51] Annex MD 2 September 2019, p. 6.
[52] *BAMB*, Framework for policies, regulations and standards, https://www.bamb2020.eu/wp-content/uploads/2019/01/BAMB-Framework-for-Policies-Regulations-and-Standards_with-Appendices.pdf, 2018, p. 1, 43.
[53] Annex MD 2 September 2019, p. 6.
[54] *Id.* at p. 7.
[55] *Id.*

12. The traceability system that was described in the previous paragraphs especially applies when demolition waste is transferred from a demolition site to a processing installation. However, it should be borne in mind that a certain amount of the demolition materials will go to sorting installations prior to being processed.[56] For the stony fraction in particular, Annex 3 of the Common Regulation for Recycled Aggregates sets out a specific quality system. If the stony fraction comes from a sorting installation for construction and demolition waste that meets the requirements of the quality system, the processor can also accept it as materials with a LERP.[57]

At this point, it is also possible to briefly consider the relevant end-of-waste criteria. While an in-depth discussion on the end-of-waste status warrants a full paper of its own[58], several criteria are relevant in view of determining when construction materials cease to be labelled as waste in Flanders: (i) the materials have left the processing plant (i.e. the location where the materials are recycled or salvaged),[59] (ii) the materials comply with the applicable waste legislation (e.g. composition conditions, maximum non-stony contamination mass)[60] and usage limitations, and (iii) the materials can no longer be considered as waste in the sense of article 3, 1. Waste Framework Directive.[61] On balance, while complexities regarding the application of the end-of-waste status remain, it does offer useful guidance to undertakings to facilitate a self-assessment.

3. The potential role for blockchain in circular waste streams

13. The introduction of a traceability system and DMOs in Flanders affirms the region's desire to 'close the loop' and to transition towards a more circular waste management cycle. However, as explained above, the construction sector presently faces a number of teething problems.[62] These issues revolve, among others, around incomplete information streams, concerns regarding inaccurate data, and the existence of information asymmetries between different actors in the supply chain. As a result, Flanders' ambitious waste processing plans

[56] It is not always feasible to adequately separate waste at the demolition site.
[57] Article 1, Annex 3 Common Regulation for Recycled Aggregates. See above at no. 12.
[58] Notwithstanding the fact that the end-of-waste status of materials is an important aspect that requires further research within the scope of the transition to a circular economy, the focus of this article is limited to adequate information and data management within the construction supply chain. Therefore, the end-of-waste status will not be discussed in detail.
[59] Report to the members of the Flemish Government concerning the Flemish Order of 17 February 2012, *Belgian Official Gazette* 23 May 2012, 4.
[60] For example: Article 36 Materials Decree and article 2.3.2.1. and following of the Flemish Order of 17 February 2012.
[61] See also: Article 3, §1, 1° Materials Decree.
[62] See above at no. 3.

(prevention, reuse, recycling, etc.) currently do not attain their full potential. On that account, it is worth considering how blockchain technology could alleviate data management problems within construction supply chains. At first sight, blockchain technology may appear to be an unlikely candidate to tackle the aforementioned challenges. Yet, when looking beyond the hype[63], one soon arrives at the understanding that distributed ledger technology harnesses some interesting features that could be leveraged to enhance existing transparency levels within the Flemish traceability procedure.

3.1. The fundamentals of blockchain-based information systems[64]

14. At its core, blockchain is an umbrella term for a cluster of different technologies that make it possible to store information in a decentralised data registry (distributed ledger).[65] An important feature of such a registry is that it only allows for new data to be added (append-only).[66] Cryptographic mechanisms (hash functions) ensure that it is not possible to modify data once it has been entered into the registry (immutability).[67] Furthermore, the ledger is designed in such a way that it will only include new information if it has been validated by a peer-to-peer network of 'miners' and if this network has correctly structured the information in a block, the fundamental unit of a blockchain.[68] Within this validation process, the network must, among others, verify that each new block contains the correct and encrypted reference (hash) of the previous block.[69] This procedure involves the solving of a complex mathematical puzzle. Finding the solution of this puzzle – the so-called nonce[70] – is required to build a valid block. Interestingly, the difficulty target of the puzzle dynamically evolves depending on the computing power available within the network.[71] In doing so, the blockchain ensures that the time interval between two different blocks being added to the ledger remains consistent, no matter how many miners are looking for the solution to the puzzle. The whole process where

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[63] *C. Mulligan* et al., Blockchain Beyond the Hype - A Practical Framework for Business Leaders, World Economic Forum White Papers (2018), pp. 3-4; *G. Ongena* et al., Blockchain-based Smart Contracts in Waste Management: A Silver Bullet?, BLED Proceedings 2018, p. 346.

[64] Paragraphs 14 - 16 build upon research findings that are published elsewhere by one of the authors. Reference to the original source: *C. Koolen*, Blockchaintechnologie, smart contracts en consumentenbescherming, in F. Hoogendijk, P.-J. Aerts & N. Vandezande (eds.) Smart contracts: een overzicht vanuit juridisch perspectief, pp. 235-237.

[65] *M. Crosby* et al., Blockchain Technology: Beyond Bitcoin, Applied Innovation Review 2016 (2), p. 8; *M. Swan*, Blockchain: Blueprint for a New Economy, 2015, pp. x-xi & 1-2.

[66] *B. Badr*, *R. Horrocks* & *X. Wu*, Blockchain by Example, 2018, p. 10; *D. Drescher*, Blockchain basics. A non-technical introduction in 25 steps, 2017, p. 240.

[67] *M. Van de Looverbosch*, Crypto-effecten: tussen droom en daad, TRV-RPS 2018, p. 194; *J. Bacon* et al., Blockchain Demystified, Queen Mary School of Law Legal Studies Research Paper No. 268/2017, p. 6.

[68] *A. Antonopoulos*, Mastering Bitcoin. Programming the Open Blockchain, 2017, pp. 27-29.

[69] *K. Christidis* & *M. Devetsikiotis*, Blockchains and Smart Contracts for the Internet of Things, IEEE 2016 (4), p. 2293; *V. Buterin*, A next generation smart contract & decentralized application platform, https://cryptorating.eu/whitepapers/Ethereum/Ethereum_white_paper.pdf, pp. 6-7 (last consulted on 20 October 2020).

[70] *A. Antonopoulos*, Mastering Bitcoin. Programming the Open Blockchain, 2017, p. 244 et seq.

[71] *Id.* at pp. 251-252.

miners add a new block to the blockchain by solving the abovementioned computational problem is called 'mining'.[72] The miner who is first to provide the correct solution receives a certain amount of cryptocurrency (such as bitcoins) as a reward.[73]

15. The result of continuous mining is that a chain of blocks is created – hence the name blockchain[74] – in such a way that the chain itself is able to guarantee the integrity of all connected blocks.[75] As soon as one character changes within one of the blocks, the reference to the previous block will no longer match and the network will be able to determine that an irregularity occurred while building a new block. In the event of such a finding, the network will simply refuse to integrate the falsified block into the registry.

16. A good way to illustrate the structure of a block is by comparing it to a page in a book[76]: each page has a unique page number and can contain a certain amount of text. Once a page is filled, it is necessary to add a new page to the book. The same applies to a block in a blockchain. Each block has a unique identification number and each block can only contain a certain volume of bytes. When taking a closer look at the content of a block, one will find information about (i) the creation of the block (e.g. version number, time stamp), (ii) a reference to the previous block in the chain, and (iii) a collection of accepted transactions.[77]

17. The way in which blockchains function offers some considerable advantages when contrasted against traditional, centralised information systems. For instance, blockchains are capable of significantly reducing the level of trust required between different intermediaries.[78] Indeed, there no longer exists a single, final authority over the blockchain, given that all records are stored and processed in a decentralised manner. Instead, all parties involved can rely on the mathematics that underpin blockchain-based systems.[79] Furthermore, whereas centralised databases remain susceptible to hacking and manipulation, these concerns are mostly[80] rendered

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[72] *D. Drescher*, Blockchain basics. A non-technical introduction in 25 steps, 2017, p. 240; *A. Antonopoulos*, Mastering Bitcoin. Programming the Open Blockchain, 2017, pp. 26-27.
[73] As a result, many individuals consider mining a lucrative business.
[74] *B. Badr*, *R. Horrocks* & *X. Wu*, Blockchain by Example, 2018, p. 10.
[75] *G. Governatori* et al., On legal contracts, imperative and declarative smart contracts, and blockchain systems, Artificial Intelligence and Law 2018 (26), p. 381.
[76] *B. Badr*, *R. Horrocks* & *X. Wu*, Blockchain by Example, 2018, p. 11.
[77] *Id.*
[78] *A. França* et al., Proposing the use of blockchain to improve the solid waste management in small municipalities, Journal of Cleaner Production 2020 (244), p. 2.
[79] *E. Mik*, Electronic Platforms: Openness, Transparency & Privacy Issues, European Review of Private Law 2019 (6), p. 858; *K. Werbach*, Trust, but Verify: Why the Blockchain Needs the Law, Berkeley Tech. L.J. 2018 (33), pp. 497-498.
[80] Consider, for instance, a so-called '51% attack'. If a single miner possesses more than 50% of the entire network's computational power, that individual can theoretically monopolize the creation of blocks. However, due to the shear amount

null due to the aforementioned puzzle-solving requirement and the immutable character of validly added blocks to the blockchain.[81] Another element worth mentioning is that blockchains are, in principle, publicly accessible via internet web browsers.[82] This implies that information added to a blockchain is visible to all stakeholders – be it a demolition company, a demolition management organisation or a property owner. This feature essentially contributes to a more transparent environment where everyone can inspect the materials' chain of custody at any given time. Additionally, new blocks are added to the chain in relatively short intervals, which implies that new data are quickly processed and made visible to everyone involved.[83]

18. However, this is not to say that blockchains are perfect. Although mathematically sound, some notable disadvantages should be considered. The arguably most important challenge is the scalability of blockchains.[84] A blockchain's success is largely dependent on the number of users that are willing to engage with the blockchain. Accordingly, if key actors within the circular waste stream are reluctant to participate, then the added benefits of using a blockchain-based information system remain rather limited. Another shortcoming of blockchains is that they often rely on a Proof of Work-validation mechanism (cf. the aforementioned puzzle-solving requirement).[85] Although crucial for tamper-proofing the blockchain environment, Proof of Work is an extremely inefficient and energy intensive process, which requires an inordinate amount of computing power.[86] Thus, while attempting to pursue a more robust circular waste stream, using blockchains may in itself run counter to current sustainability aspirations. Lastly, it should also be borne in mind that blockchain technology is still very much in development and that it remains difficult to predict how the technology will evolve in the foreseeable future.[87] At the time of writing, it is already apparent that a blockchain embodies a

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of computing power required to achieve this goal, scholarship believes that 51% attacks are unlikely to occur. In this regard, see also *P. Cuccuru*, Beyond bitcoin: an early overview on smart contracts, IJLIT 2017 (25), p. 183, fn. 12.

[81] *M. Van de Looverbosch*, Crypto-effecten: tussen droom en daad, TRV-RPS 2018, p. 205. The author explains that hacking is predominantly a concern when interacting with blockchains through means of peripheral services. Exploiting the blockchain in itself, however, proves rather difficult if not impossible when using adequate cryptography mechanisms.

[82] For instance, the entire Bitcoin blockchain is accessible via https://www.blockchain.com/explorer?view=btc.

[83] For instance, new blocks are added to the Bitcoin blockchain in 10-minute intervals.

[84] *M. Kouhizadeh*, *J. Sarkis* & *Q. Zhu*, At the Nexus of Blockchain Technology, the Circular Economy, and Product Deletion, Applied Sciences 2019 (9), p. 5.

[85] *Y. Poullet* & *H. Jacquemin*, Blockchain : une révolution pour le droit ?, Journal des Tribunaux 2018 (36), p. 803; *J. Fairfield*, Bitproperty, Cal. L. Rev. 2015, p. 822.

[86] *J. Bacon* et al., Blockchain Demystified, Queen Mary School of Law Legal Studies Research Paper No. 268/2017, p. 14 et seq: "*Researchers have estimated that Bitcoin mining consumes 100–500 MW per day, or 3–16 PJ per year. This is similar to the yearly energy expenditure of c. 200,000-1.2m EU households. A single Bitcoin transaction requires an estimated 200kWh of energy, compared to around 0.01kWh per Visa transaction*."

[87] *K. Werbach*, Trust, but Verify: Why the Blockchain Needs the Law, Berkeley Tech. L.J. 2018 (33), p. 528; *J. Wang* & *C. Lei*, Will Innovative Technology Result in Innovative Legal Frameworks? – Smart Contracts in China, European Review of Private Law 2019 (6), p. 939.

highly complex phenomenon that requires an extensive set of technical skills for its implementation.

3.2. Not all blockchains are created equal

19. Some readers are probably familiar with the Bitcoin blockchain. However, as pointed out in the previous section, blockchain is a generic term.[88] This means that different classes of blockchains exist, each with their own distinct properties and features. Consequently, it is correct to state that Bitcoin is only one particular application of blockchain technology while, in reality, a broad range of different blockchains exists. By way of illustration, reference can be made to other well-known blockchains such as Ethereum[89], Ripple[90], Hyperledger Fabric[91], and Cardano[92]. The ongoing development of blockchain technology has thus resulted in the creation of different distributed ledger architectures. Broadly speaking, these distinct types of architectures can be separated along the lines of two different variables: public versus private blockchains, on the one hand, and permissionless versus permissioned blockchains, on the other hand.[93]

20. As the name suggests, a public blockchain is accessible to everyone that knows of its existence.[94] Data written to the ledger are publicly available and it is relatively straightforward for anyone to participate in the network, thereby obtaining a local copy of the distributed ledger. Once a user has obtained a full copy of the ledger, they are called a 'node' in the blockchain.[95] The role of a node is essentially twofold. Firstly, having a dedicated copy of the ledger means that nodes can preserve and distribute the information contained in the ledger. Secondly, nodes also allow for integrity checks to be performed by other nodes, since all nodes must, by definition, have an identical copy of the ledger. As a result, public blockchains offer an elevated level of transparency.[96] Conversely, private blockchains rely on assorted protection mechanisms to preclude the public from accessing the ledger.[97] Instead, only pre-approved

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[88] See above at no. 17.
[89] https://ethereum.org/en/.
[90] https://ripple.com/.
[91] https://www.hyperledger.org/use/fabric.
[92] https://cardano.org/.
[93] *K. Vingerhoets*, Van gedeeld grootboek tot blockchain, in F. Hoogendijk, P.-J. Aerts & N. Vandezande (eds.) Smart contracts: een overzicht vanuit juridisch perspectief, pp. 26-30; *R. De Caria*, The Legal Meaning of Smart Contracts, European Review of Private Law 2019 (6), p. 732; *E. Mik*, Electronic Platforms: Openness, Transparency & Privacy Issues, European Review of Private Law 2019 (6), p. 857 et seq; *B. Badr*, *R. Horrocks* & *X. Wu*, Blockchain by Example, 2018, p. 300.
[94] *B. Badr*, *R. Horrocks* & *X. Wu*, Blockchain by Example, 2018, p. 300.
[95] In layman's terms, nodes can be understood as small data servers that store the entire distributed ledger and that are connected to other nodes, which also have their own copy of the ledger.
[96] *P. Cuccuru*, Beyond bitcoin: an early overview on smart contracts, IJLIT 2017 (25), p. 182.
[97] *Id.* at p. 192.

parties have the option to become a node in the network and to access information stored on the chain.[98] For those reasons, the usage of private blockchains is commonplace in commercial settings, where sensitive information needs to be safely stored and shared between predetermined parties, while precluding access to outsiders and while maintaining the advantages[99] of distributed ledger technology.[100]

21. The difference between permissionless and permissioned blockchains relates to varying user rights within the blockchain environment.[101] In a permissionless system, all nodes possess equal access and use rights.[102] The implications thereof are twofold. Firstly, all nodes can add information to the ledger if they correctly assemble a new block. Secondly, those same nodes are also collectively responsible for the administration and maintenance of the blockchain on the protocol level (i.e. the underlying rules[103] that dictate how the blockchain operates). In other words, there does not exist a separate, centralized user with administrator privileges over the blockchain protocol. Instead, the management of the blockchain itself takes place in a decentralised fashion, typically by keeping all parties mutually distrustful of one another while simultaneously providing economic incentives to keep everyone honest.[104] The opposite applies to permissioned blockchains. Permissioned systems are typified by the involvement of particular nodes that hold higher privileges vis-à-vis all other nodes.[105] These administrator users are responsible for managing the blockchain protocol and determining the access, reading, and writing permissions of regular nodes within the network.[106] In practice, this implies that the processing of transactions within a permissioned blockchain can be limited to pre-approved participants with specific rights.[107] However, it needs to be emphasized that, despite the

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[98] *K. Vingerhoets*, Van gedeeld grootboek tot blockchain, in F. Hoogendijk, P.-J. Aerts & N. Vandezande (eds.) Smart contracts: een overzicht vanuit juridisch perspectief, p. 27; *B. Badr*, *R. Horrocks* & *X. Wu*, Blockchain by Example, 2018, p. 301.

[99] Notably the immutability and append-only features. See above at no. 17.

[100] *E. Mik*, Electronic Platforms: Openness, Transparency & Privacy Issues, European Review of Private Law 2019 (6), p. 859 who writes the following: "*The complete transparency of information [of permissionless blockchains] contradicts [...] commercially and legally important requirements as confidentiality and privacy*".

[101] *K. Vingerhoets*, Van gedeeld grootboek tot blockchain, in F. Hoogendijk, P.-J. Aerts & N. Vandezande (eds.) Smart contracts: een overzicht vanuit juridisch perspectief, pp. 28-29.

[102] *E. Mik*, Electronic Platforms: Openness, Transparency & Privacy Issues, European Review of Private Law 2019 (6), p. 858.

[103] Typical rules at the blockchain protocol level concern (i) the nature of the blockchain (i.e. public or private, permissioned or permissionless), (ii) the structure and exchange of information, (iii) cryptography techniques, (iv) the consensus algorithm, and (v) user permissions.

[104] *Id.*; *B. Badr*, *R. Horrocks* & *X. Wu*, Blockchain by Example, 2018, p. 300.

[105] *M-C Janssens* & *J. Vanherpe*, Blockchain and copyright - Beyond the buzzword?, Intellectuele Rechten/Droits Intellectuels 2018 (2), p. 97.

[106] *T. Cutts*, Smart Contracts and Consumers, LSE Law, Society and Economy Working Papers 1/2019, p. 25: "*Permissioned systems might usefully be illustrated by way of a Google Doc: a document can be set up so that a variety of persons may view or edit, while the infrastructure that allows the document to be created is maintained by a single company*".

[107] *E. Mik*, Electronic Platforms: Openness, Transparency & Privacy Issues, European Review of Private Law 2019 (6), p. 859.

existence of an administrator role, all information is still processed in a decentralised manner and subjected to the usual peer-to-peer network validation process.

22. It follows from the above that blockchain technology offers a high level of customisability. With the necessary technical skills and knowhow, entities could effectively create their own blockchain and mould it from an off-the-shelf technology into a target specific tool. The degree of flexibility offered by distributed ledger technology to design blockchains to one's needs and wants also explains why the underlying technology is gaining traction in a wide variety of commercial sectors such as pharmaceuticals, food safety, jewellery, and transportation. In the same vein, blockchains can also provide a meaningful contribution to enhancing the efficacy of waste streams and turning waste processes into more circular business models by means of better information management.

3.3. Aligning blockchain technology with the construction sector

23. In our view, the usage of public permissioned blockchains can considerably improve existing traceability procedures within waste processing streams. Making use of a permissioned system has some notable advantages. For instance, adding a control layer essentially guarantees the proper organisation and governance of the blockchain. In the case of circular waste streams, the role of such a central authority could lay with an accredited regulatory institution or a dedicated non-profit organization such as a DMO. This governing body could subsequently determine what information is stored in the ledger and how it is structured. Registered data could include (i) references to the type and quantity of recycled construction materials, (ii) labels that indicate the presence of toxic substances, (iii) transport documents, (iv) certificates of demolition, etc.

24. Apart from a governing body, other commercial actors involved in the circular supply chain – including demolition companies, waste aggregators, and transportation businesses – could be considered regular nodes in the network. This eventually leads to a situation where all actors can rely on a very open and transparent information sharing system. Furthermore, given that data can be shared across the distributed network without much effort, everyone involved also has the possibility to check whether information entered in the ledger is genuine and factually correct.[108] The public character of the blockchain also allows for non-stakeholder

[108] *K. Christidis & M. Devetsikiotis*, Blockchains and Smart Contracts for the Internet of Things, IEEE Access 2016, 2296.

actors to consult the ledger, thereby effectively enabling end-to-end information sharing without the involvement of any additional steps.[109] In turn, this feature also has the added benefit of serving as a potential signalling tool to the outside world, shedding light on those companies that are truly pursuing circular practices.[110]

25. In the context of demolition projects, it often happens that non-textual information (e.g. structural drawings) is available for storage as well. This triggers the question how the depository of such documents takes place in a blockchain environment. At the outset, it needs to be pointed out that blockchains are not particularly well suited for storing visuals such as images and graphs due to block size limitations.[111] To address this issue, one can either rely on intermediary steps before storing an image in the blockchain or opt for *off chain* storage.[112] In the former scenario, the image is compressed and broken down into its hexadecimal code[113] before being entered into a block as per usual.[114] In the latter scenario, one only stores the reference (hash) to the image on the blockchain, while the image itself is stored elsewhere (e.g. in a distributed file storage system or external database).[115] In this case, the image will remain accessible at the specified location and the hash taken up the blockchain provides the necessary means to check that the image is original and that it has not been tampered with.

3.4. Tokenization

26. Choosing for a public permissioned blockchain topology leads to a situation where it becomes easy to identify the different stages of a waste management process, the recovered/recycled materials, and all parties involved in the waste management supply chain. However, at this point, one might wonder how blockchains are capable of bridging the gap between the digital realm and the real world. In other words, how does a company integrate

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[109] *S. Mondal* et al., Blockchain Inspired RFID-Based Information Architecture for Food Supply Chain, IEEE Internet of Things Journal 2019 (6), p. 5804.

[110] *M. Kouhizadeh*, *J. Sarkis* & *Q. Zhu*, At the Nexus of Blockchain Technology, the Circular Economy, and Product Deletion, Applied Sciences 2019 (9), p. 5.

[111] For instance, the Bitcoin blockchain has a block size limit of roughly one megabyte, whereas technical drawings can easily take up a multiple of this number in terms of file size.

[112] Consider, for instance, Tracimat's digital platform where specific documents relating to demolition projects (e.g. pre-demolition inventory, processing authorization, etc.) can be stored: https://www.tracimat.be/digitaal-platform/.

[113] The reader can check for himself or herself how documents can be converted into hexadecimal code by searching the internet for "file to hexadecimal converters".

[114] Depending on the size and resolution of an image, its hexadecimal code can be spread across multiple blocks if needs to be. While this strategy works in practice, it is quite circuitous and, moreover, introduces a high amount of latency in the blockchain environment while also imposing high processing costs.

[115] While this detracts of the principle of decentralisation to some extent, it is by far the most efficient way to store non-textual information; *B. Whittle*, Storing Documents on the Blockchain: Why, How, and Where, https://coincentral.com/storing-documents-on-the-blockchain-why-how-and-where (last consulted on 26 January 2021).

data from a physical waste stream into a digital blockchain platform? In order to answer this question, it is necessary to briefly touch on 'tokens' and the phenomenon of tokenisation.[116]

27. According to NARAYAN and TIDSTRÖM, "*[t]okenization in the blockchain is a process of converting the rights to an asset into a digital token, which facilitates the trading of those assets […]*".[117] Stated otherwise, within a blockchain environment, real worlds assets are represented through means of tokens. These tokens are best understood as purely digital objects through which it is possible to designate a certain value.[118] The fact that tokens are value bearing makes them highly suitable for trading via the blockchain. Thus, while a blockchain is unable to transfer assets that exist in the real world, it is capable of facilitating a trade of the underlying token that digitally represents the asset.

28. In practice, tokenisation takes place by tagging physical objects – for instance a cargo container – with machine readable RFID-chips or QR-codes.[119] In doing so, it not only becomes possible to uniquely identify physical objects within the blockchain, but also to associate other information to it (e.g. registering the cargo tonnage when a truck drives over a weighing bridge, or determining the presence of toxic substances) and even register movement (e.g. when a cargo container enters or leaves the processing plant). In the context of circular waste management, the features of tokenisation enable stakeholders to trace waste compounds within the supply chain and to oversee all relevant steps of the overall waste management process. For instance, if party A is responsible for adding the cargo weight to the blockchain, party B can verify this information on his own motion before starting with their own processing tasks. If party B is subsequently responsible for separating the cargo into different waste fractions (e.g. plastic, metal, wood), party C can check whether the separation process has been conducted diligently. Thus, due to the transparent character of the blockchain, all supply chain actors have the ability to double check whether information entered into the ledger is both genuine and accurate.[120]

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[116] *B. Badr*, *R. Horrocks* & *X. Wu*, Blockchain by Example, 2018, p. 6; *Y. Poullet* & *H. Jacquemin*, Blockchain : une révolution pour le droit ?, Journal des Tribunaux 2018 (36), p. 815; *K. Werbach* & *N. Cornell*, Contracts ex machine, Duke Law Journal 2017, pp. 334-335.
[117] *R. Narayan* & *A. Tidström*, Tokenizing coopetition in a blockchain for a transition to circular economy, Journal of Cleaner Production 202 (263), p. 2.
[118] *C. Koolen*, Blockchaintechnologie, smart contracts en consumentenbescherming, in F. Hoogendijk, P.-J. Aerts & N. Vandezande (eds.) Smart contracts: een overzicht vanuit juridisch perspectief, pp. 240-241.
[119] *S. Latif*, *A. Rehman* & *N. A. Zafar*, Blockchain and IoT Based Formal Model of Smart Waste Management System Using TLA+, International Conference on Frontiers of Information Technology 2019, p. 305; *S. Mondal* et al., Blockchain Inspired RFID-Based Information Architecture for Food Supply Chain, IEEE Internet of Things Journal 2019 (6), pp. 5803-5804; *R. Narayan* & *A. Tidström*, Tokenizing coopetition in a blockchain for a transition to circular economy, Journal of Cleaner Production 2020 (263), p. 5.
[120] *K. Christidis* & *M. Devetsikiotis*, Blockchains and Smart Contracts for the Internet of Things, IEEE Access 2016, p. 2296.

When information does not add up, it only takes little effort to demonstrate where and by whom errors have been made. As a corollary, the trend of tokenising waste stream fractions also contributes towards a more open and transparent market where by-products and secondary products of the waste management process can be traded without much effort.[121] This essentially opens the door to get more actors involved in the circular supply chain.

4. Discussion

29. The previous sections scrutinized the traceability procedure of construction and demolition waste in accordance with the Flemish material legislation and the theoretical underpinnings of blockchain technology. We are not the first authors who attempt to link blockchain technology to circular construction practices.[122] However, existing contributions mostly focus on the construction supply chain, without taking a detailed look at the overall management implications of processing construction and demolition waste (i.e. the implications that arise once a building has reached the end of its life). While understandable from a research perspective[123], the transition to a circular economy also requires new ideas and practices concerning waste management.

The proposed combination of quality management (i.e. a traceability procedure) and data management (i.e. a blockchain) leads to interesting and circular results. Reliance on an extensive preplanned demolition is possible due to accurate data being readily available in the blockchain-based environment, while the (Flemish) traceability procedure makes it possible to ascertain the quality of the demolition materials up to the point when they reach their destination for further processing. Hence, synergies emerge when combining both systems.

Another point worth noting is that buildings typically consist of various types of components and materials. For some specific materials, reuse instead of demolition could be considered (SHOJAEI *et al*. mention HVAC installations by means of illustration).[124] What is interesting is that several materials suitable for reuse remain uniquely distinguishable during the entirety of

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121 *M. Kouhizadeh*, *J. Sarkis* & *Q. Zhu*, At the Nexus of Blockchain Technology, the Circular Economy, and Product Deletion, Applied Sciences 2019 (9), p. 10.
122 See above at no. 3.
123 There are always some constraints (time, resources) which will make it difficult to study or research all elements of a circular economy.
124 Reuse is considered to be more interesting than recycling from a circular viewpoint. In the case of reuse, the materials are not considered to be waste.

the construction supply chain. This makes it possible to not only close the loop once, but also to continue following these materials throughout the blockchain for a second or even third life cycle. Other materials, such as concrete slabs, are commonly recycled as such. For these recycling purposes, the combination of a traceability procedure and a blockchain can guarantee qualitative and accurate information up until the point when the materials are received by the processor. The concrete slabs are subsequently crushed to granules and mixed with other granules, thereby making it impossible to keep track of the initial materials in the blockchain environment. Although the initial loop is now closed, a new avenue to track the freshly recycled granules via the blockchain also opens. All relevant information pertaining to these recycled granules can be assigned to a new variable, which is subsequently ascribed to a token in the blockchain environment. From here onwards, the circle starts again.

30. Apart from the extensive preplanned demolition, intertwining blockchain technology with the traceability procedure in Flanders also leads to the availability of more data which can incentivise other circular initiatives. For instance, trade platforms for reused or recycled construction and demolition materials could come into existence. Similarly, local or regional recycling hubs could emerge for the purpose of pooling various recycled materials into bigger volumes, thereby drawing more attention to these materials for large-scale construction projects. Aside from the abovementioned advantages, blockchain technology could also help authorities to keep track of the (preparation for) reuse and recycling target(s) mentioned in the Waste Framework Directive.[125]

31. While the integration of blockchain technology in waste management practices offers notable advantages, blockchain-based information systems are far from flawless. Firstly, blockchains pose considerable practical issues. At the time of writing, and as mentioned in section 3, it is difficult to incorporate visuals and documents into a distributed ledger environment. In construction (or demolition) projects, these files include a lot of valuable information. However, it is worth noting that blockchain technology is still in its infancy and that it has only recently sparked the interest of policymakers and innovators alike. While the technology will undoubtedly keep developing in the coming years, it is difficult to predict what blockchains will and will not be able to do in the near future. Another issue relates to the lack

[125] Article 11, 2. (b) Directive 2008/98/EG.

of a coherent legal framework for the use of blockchain technology.[126] For example, the Flemish legislation on the traceability procedure does not consider the use of blockchain technology and, more generally, does not stimulate nor facilitate the use of technological innovations within the context of waste management.[127]

As a final note, we would like to emphasise that blockchain technology is not the only pathway to more circular practices in the construction sector. Other systems for data management can be viable as well. Nowadays, the Flemish traceability procedure works in a somewhat analogous way. This methodology can certainly lead to adequate results, albeit without offering the abovementioned advantages of blockchain technology.[128] In addition, research focused on BAMB (Building As Material Banks) and the use of material passports also shows promising opportunities.[129]

5. Concluding thoughts

32. Linking blockchain technology to the traceability procedure in Flanders can foster more trust and cooperation throughout the supply chain by means of better information processing and data availability. It gives society an opportunity to boost current circular ambitions by fully 'closing the loop' and by not having to halt circular practices at the construction phase of a building. However, the abovementioned elements simultaneously make it clear that blockchains and traceability procedures are not a perfect match. Nevertheless, we look forward to further advancements in the field. In an effort to further bridge the gap between 'demolition' and 'construction', demolition management organisations (DMOs) could perhaps gradually evolve into 'Construction Management Organisations' (CMOs), which can secure data flows and information processing throughout the full life cycle of a building and its materials. Another interesting pathway for further exploration is the establishment of a link between blockchains and BIM (Building Information Modelling).[130]

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[126] This is also mentioned in: *A. Tezel, E. Papadonikolaki, I. Yitmen, P. Hilletofth*, Preparing construction supply chains for blockchain technology: An investigation of its potential and future directions, Frontiers of Engineering Management, 2020 (7), p. 547, 550.

[127] The draft of the coming revision of the Flemish Order suggests that this is about to change (digital identification forms): *OVAM*, Vlarema 8: Verplichte sloopopvolging met traceersysteem om puin beter te recycleren, 2021, https://www.ovam.be/vlarema-8-verplichte-sloopopvolging-met-traceersysteem-om-puin-beter-te-recycleren.

[128] However, it is considered to be necessary to take further legislative action to make this process run more smoothly: *Minaraad*, Advies wijziging 8 VLAREMA, 2021, https://www.minaraad.be/themas/materialen/vlarema-8, 9; *OVAM* , Op weg naar circulair bouwen, 2021, preliminary working paper, p. 16 and following.

[129] For more information: https://www.bamb2020.eu/

[130] See for example: *ARUP*, Blockchain and the built environment, 2019, https://www.arup.com/perspectives/publications/research/section/blockchain-and-the-built-environment, 40.

33. In conclusion, blockchain technology undeniably alleviates some of the existing problems that emerge when managing (stony) waste streams in Flanders and beyond. At the same time, however, it was shown that blockchains are not a panacea for all ills pertaining to the traceability of waste streams. Yet, when considering these finding as a whole, one can only hope that this contribution provides the necessary level of encouragement to stakeholders to review how blockchain technology can be leveraged in pursuit of society's future sustainability endeavours.