# CONJUGATED MATERIALITY - REINSTATING MATERIAL CIRCULARITY VIA DIGITAL TWINS

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**Abstract.** Industrial Revolution 4.0 offers an opportunity for the globe to rethink the meaning of building information that breaks the territorial borders of building information systems that are not based project-wise but follow a geopolitical structure. It expands the conventional thought process of being limited to a building to a city/ planetary urbanisation level. As a response to the new urban design theory, the paper posits an approach that amalgamates "Design for Disassembly (DFD)" and "Digital Twins" which have gained traction because of "Circular Economy" and "Industrial Revolution 4.0" respectively, to create an information framework for the urban ecology that focuses on system management rather than project management via "Material Passport (MP) 2.0". It identifies the gaps within the existing MP and creates a foundational framework for the added information (termed "Material Strategies") that needs to be a part of MP 2.0 that arise while working across systems by augmenting DFD and Digital Twins via the lens of materials. The material strategies are further investigated through a correlation matrix to understand their interdependency to finally create a JavaScript Object Notation (JSON)-based serialisation of materials to reinstate the material circularity and reduce the carbon emissions that the construction sector accounts for.

**Keywords.** Design for Disassembly (DFD), Digital Twin, Material Passport (MP), Circular Economy, JavaScript Object Notation (JSON)

## 1. Introduction

The paper, by positioning itself amidst the "New Materiality" (considering materials as active entities and believing in systems rather than symbols or objects that is line with DFD) and "Cybernetics" (concerned with circular causality or regular feedback, in line with Digital Twins) theories, seeks to create an information framework for the environment based on cross machine interaction and machine intelligence where the role of human becomes secondary. This information framework is primarily based on "Material Strategies", that the paper generates, and which form the foundation of MP 2.0. The paper further highlights their need in order to break from the transcendental notion of working within a single system to work across systems. It then understands

their interdependency via matrix analysis and further depicts where these strategies and the parameters associated with them are interjected while working across systems. To cater to the complexity established during this process, the paper attempts at creating a material serialisation that is based on JSON (a computationally sustainable language) for cataloguing and tracking the complex materiality of the building processes. It envisions at reinstating the material circularity within a derailed construction industry by creating a "Digital Material Passport" that uses the digital twin technology to help in reducing carbon emissions at a planetary level.

As the world is entering into an era where systems are run and monitored by machines known as the Cyber-physical systems (CPS), it offers a possibility to remodel the construction industry that considers city and the planet as a mega building project rather than just limiting to a building. The industry's constant emphasis on the recognition and creation of "symbols" (as suggested by the old dialectical materialism by Marx and Hegel) i.e., the overall meaning and the outlook of the building, without giving much importance to the underlying "process" such as the interactions between various materials involved within the same building have rendered the industry less sustainable and linear (consuming 40% and wasting 30% of resources). The result is that materials either end up being downcycled or in landfills when paving way for newer construction thus following the loss of embodied carbon (releasing nearly 11% of the world's carbon into the atmosphere). The need therefore is to shift from the notion of project management (passive perception of materials) to system management (active perception of materials) which "New Materiality" (synonymous with the theory of “New Materialism”) by Manuel DeLanda based on the work of Deleuze and Guattari argues and is addressed by the concepts of DFD and Digital twins to assist in achieving the goal of a "Global Circular Economy".

## 2. Background

New Materiality brought forward the concept of "active materiality" that categorises systems not only by properties but also by their capacities/ tendencies which can be real without being actual, ontologically defined as "virtual", requiring a catalyst to bring them to actuality (DeLanda, 2015). DFD, which focuses on formation rather than form, treating materials as active entities that are dynamic rather than objects that are constant, within and across systems and emphasises material information as MPs rather than the structure, aligns with this theory but however addresses only a part of it. With the advent of CPS, Digital Twins which has garnered traction as a part of Industrial Revolution 4.0, offers the possibility of perceiving and bringing the virtual tendencies that exist within a material (what was, what is and what can be) to actuality by acting as a catalyst. Industrial Revolution 3.0 revolutionised the physical space by introducing a parallel virtual space in the 20th century with the introduction of computers, the internet, wireless networks, and simulation tools that not only enabled remote cooperation between the virtualized physical assets but also plans and operations more effective and efficient (Tao and Zhang, 2017). Digital twins unveil this shroud of virtual intelligence that is associated with each object and can blur the boundary between the virtual and physical which until now were considered as two separate faces of the same coin. The aim of a digital twin is to create high-fidelity virtual models to imitate the state and the behaviours of each of the physical objects with the ability to evaluate,

optimise and predict (Graessler and Pöhler, 2017), which is the reason feedback and information are its essential components to guide physical entities to their optimal states. This description is however analogous with the theory of Cybernetics that recognises the world based on information and control by means of "circular causality" or in simple terms feedback. By playing out multiple scenarios based on constant feedback and avoiding the unintended consequences that are often brought with the well-intentioned changes, digital twins provide a testing bed of experimentation without having to make changes in the real life that can reduce greenhouse gas emissions and cost savings by 50% and 35% respectively according to research carried out by the professional services company EY (Ernst and Young).

Industrial Revolution 4.0 which highlights cross-communication across machines, needs a regular information exchange across the web making good data interoperability necessary. XML (Extensible Markup Language) and JSON are currently the most common data formats that are used for this cybernetic purpose which the paper acknowledges. BIM (Building Information Modelling), the foundation of Digital Twin, uses XML for this purpose. XML is the most widely used format across programmes, people, people and machines for sharing structured information i.e., data, documents, books, transactions, invoices, etc. Industrial Revolution 4.0 which is heavily reliant on data requires significant storage and parsing space. The more complex the data, the more data centres it requires and the more carbon emissions it produces. According to studies, JSON (whose syntax is both human and machine-readable) has proven to be computationally sustainable requiring lesser data storage space when compared to XML which can significantly reduce carbon emissions. The paper, therefore, suggests JSON as a better alternative for information exchange in Industrial Revolution 4.0 which is also the reason why Table 1 shows examples that are JSON formatted BIM data.

| Name | Purpose | Focus |
|---|---|---|
| vA3C | Plugin exported BIM data from SketchUp, 3DS Max, Revit, Grasshopper, etc. is converted to JSON using a browser-based open-source BIM model viewer vA3C that uses a customised JSON schema definition which focuses exclusively on geometry data while producing documents (vA3C, 2022). | Objects |
| Autodesk Forge Viewer | Employing its own unique JSON schema definition, it translates 2D and 3D models of more than 70 file formats, including AutoCAD, Fusion360, Revit, etc., to JSON (Forge, 2022). | Objects |
| GeoJSON | It supports several geometry data types like LineString, MultiString, Point, MultiPoint, Polygon, and MultiPolygon even though its primary use is to serialise geographic data. The only drawback being the term "properties" which is overly general when it comes to complex geometry that does not address building data component specification. | Geographic Information (GIS) |

| | | |
|---|---|---|
| ArchiJSON | It is a protocol for exchanging parameters and data for architectural design that is based on JSON (PyPI, 2021). | Objects |
| BIMJSON | It is used for exchanging BIM/ MVBs (Minimal Viable BIMs) with the primary goal to design a simple framework that is easy to grasp and has a lot of flexibility for data transfers. | Objects |

*Table 1. Past attempts*

Approaches such as DFD (since 19th century (Herbert, 1978)) and Digital Twins (since 2002 (Grieves, 2016)) are past concepts that are gaining prominence today because of the entropy bill that is coming due for which the first and the second industrial revolutions are majorly responsible for. The industrial way of life that was propelled by burning fossil fuels (coal and oil) for almost 200 years has released massive amounts of carbon dioxide which has led Anthropos to a planetary crisis of untold proportions (Rifkin, 2011). However, these approaches need to be augmented and integrated in order to reach a "Global Circular Economy", something which the entire world is striving to achieve. A coalescence is created between the two dichotomies i.e., DFD and Digital twins that are discussed in this research via JSON to generate a procedural and knowledge framework for machines in the form of MP 2.0 which addresses environment by assisting in reducing carbon emissions.

DFD questions the permanence of architectural design (relegated by style, image, and aesthetics), by being a systematic and comprehensive method that seeks to make the design as simple as possible so as to disassemble it into its component elements enabling them to stay in a closed material cycle for their reuse, reassembly, and recycling/ upcycling (Merrild et al., 2016). However, the approach still focuses on how a single project should be managed and doesn't mention or work across buildings or cities or even the earth which according to studies is even considered as a mega-building project. It needs to be augmented for the same reason so that it shifts from the notion of project management to system management. In 2015, BAMB (Buildings as Material Banks), an innovation effort sponsored by the EU's Horizon 2020 programme whose primary focus is to reduce the speed of resource consumption and squandering by turning structures of the construction sector into sources of useful materials, proposed some strategies that DFD considers. BAMB works towards a shared objective of implementing adaptable and dynamic circular solutions by 15 partners from 7 different nations across Europe.

## 3. Formulation of Material Passport 2.0 (MP 2.0)

### 3.1. CREATING MATERIAL STRATEGIES – REASSESSING DFD

We start by rethinking DFD approach from the lens of materials which focuses on materials from the outset. DFD strategy “Materials” which suggests the usage of pure, non-toxic, and resilient materials that can sustain multiple life cycles is translated into “Material Selection”. The strategy “Service Life” suggests flexibility, adaptability, and temporary structures for easy extraction of materials in translated into “Material Interaction”. The “Deconstruction” strategy, which suggests the formulation of a

deconstruction plan, environment, and material management is translated into "Material Movement". The strategy "Connections" which suggests visible, accessible, avoiding/ providing dissolvable binds, and mechanical connections to reduce time and minimal damage to materials are translated to "Material Correlation". The last strategy "Standards" which suggests using modular, easily replaceable systems, subdividing a complex structure into components, and using a prefabrication process for assembly/ disassembly to be quick and safe is translated into "Material Interaction". A depiction of the DFD strategies considered according to BAMB and their translation into Material strategies is done in Figure 1.

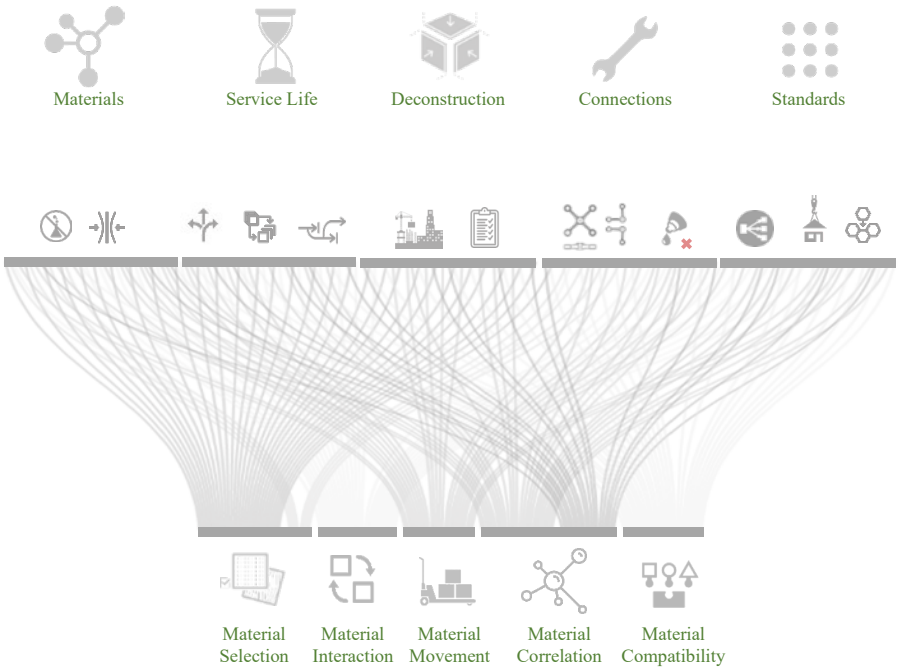


*Figure 1. Author's interpretation of translation of DFD strategies to Material Strategies*

This is however analogous with the theory of New Materiality which suggests moving away from the transcendental view of the matter to viewing and understanding them in terms of interactions, flows, and processes. A stepwise strategy is established i.e., selected materials for a system are checked for compatibility and then correlated to interact with each other. These correlated junctions can be disassembled to obtain the interacted materials separately which can then be moved and modified to interact with other systems. To be scaled across systems, and reduce time and carbon emissions, many parameters arise when materials from one system are disassembled and modified to be a part of another system. The parameters associated with each of these strategies are established using a correlation matrix in Figure 2.

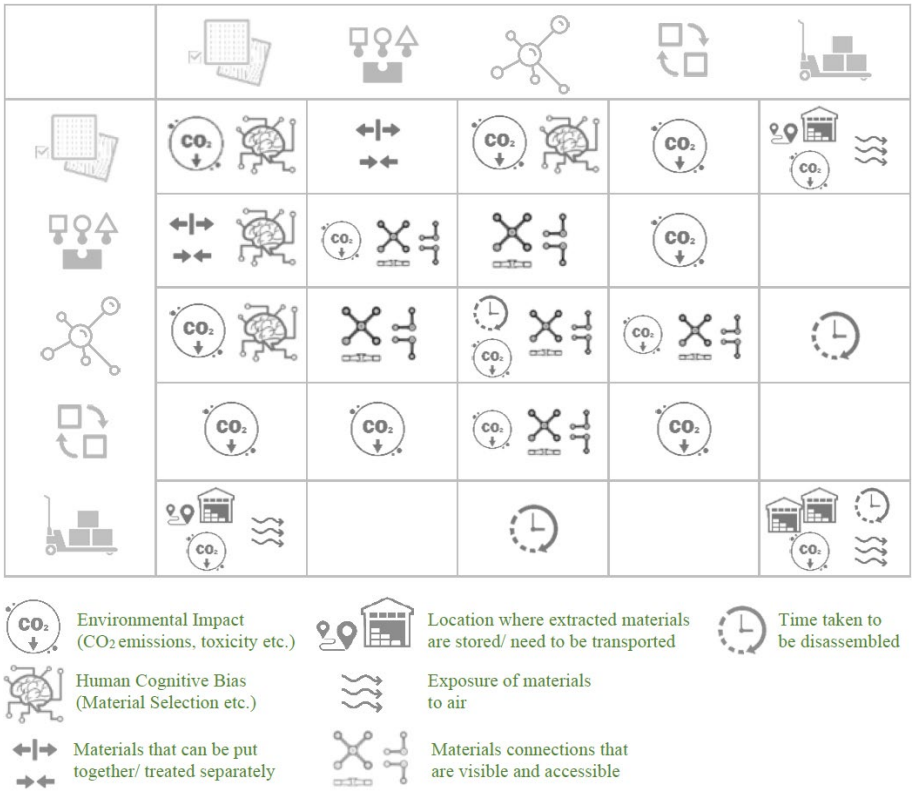


*Figure 2. Correlation matrix between Material Strategies and the parameters associated with them*

aterial information as MP is important for creating DFD designs which are catalogues that keep traces of a product's, material's, or system's activities from manufacturing, acquiring, and usage to upkeep for their potential for recovery and make that information easily accessible to the necessary parties throughout their value chain (Luscuere, 2017) for which they require to be updated regularly for their use in subsequent lifecycles. However, the current MPs are addressed only in terms of interaction within a single system while there are several parameters that arise as a result of interactions across systems that can significantly reduce the time taken during the disassembling process and reduce the carbon emissions that are associated with the disassembling process as shown in Figure 3. The correlation matrix in Figure 2, thus helps in creating the foundational framework for the information that needs to be a part of MP 2.0 which could give an added dimension to the existing MP.

The reason for understanding the intensity of materials using the correlation matrix is to reduce the time and carbon emissions when materials are disassembled from one system and are modified to be a part of another system. Figure 3 highlights the complexity involved in this process across two systems which when scaled can increase manifold, which is why the establishment of the correlation matrix is necessary. Another factor that this augmentation has highlighted is the need for the

integration of geographical information (GIS) in the current model for tracking the changes that happen to a material. Parameters that are established such as the location of the storage of the extracted materials, time taken, etc. that are related to the strategy of material movement essentially require access to this information. This also highlights why the attempts as highlighted in Table 1 do not work for Industrial Revolution 4.0 as they focus either on objects or geographical information rather their integration.

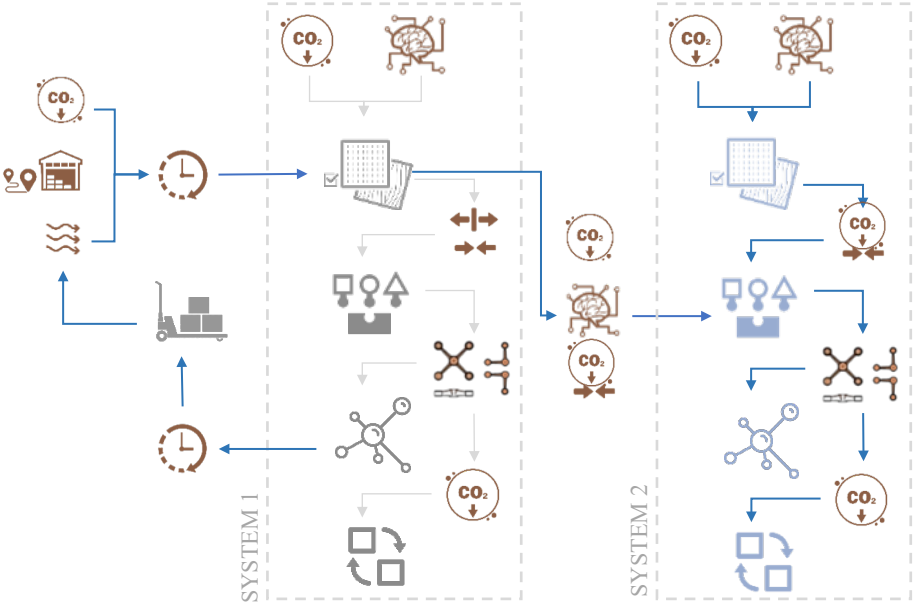


*Figure 3. Steps and processes involved during the assembly and disassembly of a system highlighting the material interactions across systems*

## 3.2. ANALYSING THE DIGITAL EXPRESSION OF MP 2.0

In the scenario of MP 2.0, the real-time updating would require information exchange via the web which further would need a comprehensive and integrated system for the exchange of information to be effective. Communication, cooperation, and exchanging data for achieving a common goal are the primary objectives of any system integration with the first and the most crucial step being data interoperability. In the case of BIM which is the base for the creation of Digital Twins for materials for the MP 2.0, this happens with the help of IFC (Industry Foundation Class) which has also been acknowledged as the de facto open BIM standard by more than 20 vendors. For the case of BIM, presently the information is exchanged in the form of BIM objects using the XML format. As stated earlier, JSON has proven to be computationally inexpensive and seems like a better alternative, especially after establishing the complexity that is involved in the creation of MP 2.0. The research envisions a transformed industry where each building/ urban setting has a digital twin at a macro level that can be carefully perceived as a composition of several material twins at a

micro level that can catalogue and track the complex materiality of the building processes to rethink the material circularity and can complement DFD and MPs as discussed in this section via JSON (for cross-communication across machines).

### *3.2.1. JSON/ XML – The Difference that Matters*

Although today, XML is one of the most widely used formats for information exchange, JSON proves to be a better alternative. The reason being XML was primarily designed to represent structured documents rather than structured data. The data structure can be visualised as trees that are exchanged across the web, out of which the relevant objects/ elements are extracted. The constant shifting between the tree (XML representation of data) and the object model (internal representation of data in applications) resulted to be more time-consuming. JSON on the other hand was developed simply by reusing the object model of an existing language (in this case JavaScript) that eliminated the need of traversing and parsing through the XML trees and allowed native data structures to directly map the JSON objects.

## 3.3. DESIGNING THE MP 2.0 SCHEMA

In order to create a global network of materials for cross-communication across various systems via machines, MP 2.0 is a framework of information for the environment that integrates BIM and GIS to create a virtual twin of materials in order to further enhance and complement the "Active Materiality" that DFD has brought to the fore. It is established on the basis of the findings in the above sections so as to reduce global carbon emissions and assist in achieving the goal of the global circular economy. Figure 4 gives a glimpse of how this cross-machine exchange of information might look like across systems.

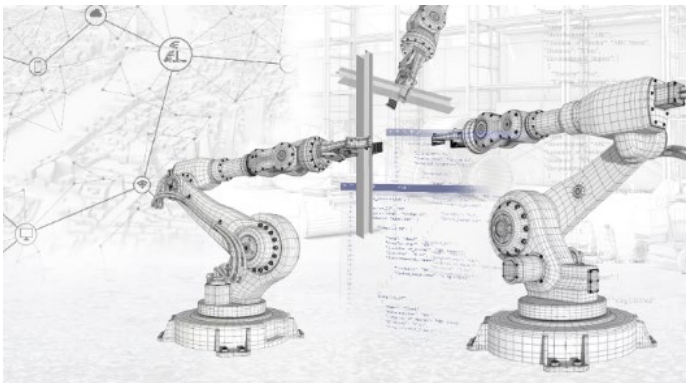

*Figure 4. Glimpse of how the new MP 2.0 works across systems*

A prototype JSON file has been validated using the JSON validator and formatter (Validator, 2022) while the JSON Schema is validated using the JSON Schema Validator (Newtonsoft, 2022) The entire file can be viewed on the following link – https://github.com/ConjugatedMateriality/MP_2.0. A graphical representation of the JSON design is depicted in Figure 5.

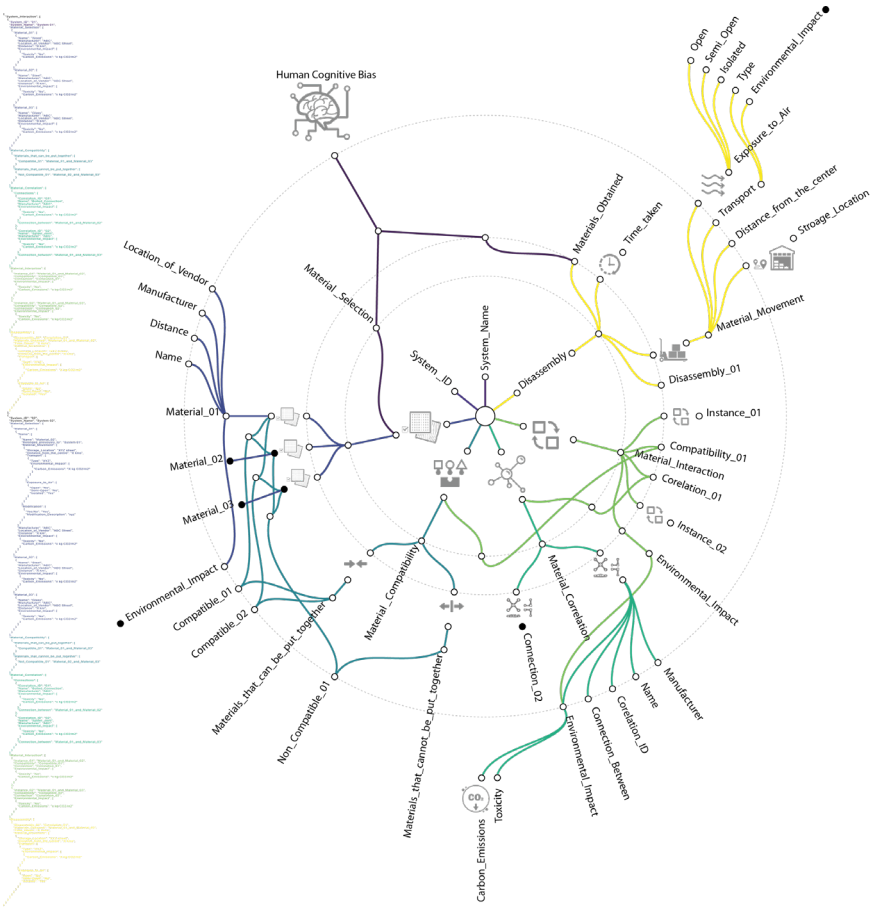


*Figure 5. A visual representation of the JSON designed MP 2.0 (Note: Full resolution image can be viewed on the github link)*

## 4. Conclusion

Increased carbon emissions and the potential planetary trauma that is looming as a result of the Anthropocene, have urged the globe to push all sectors, especially the building sector which accounts for more than a third of the world's carbon emissions, to find new approaches that help in attaining "Global Circular Economy". DFD, which focuses primarily on material information in the form of MP, is the recent approach that has been garnering traction to bring this vision to reality. The reason is a notional shift from project to system management and treatment of materials as active entities which is synonymous with the “New Materiality” theory. The same theory which suggests the requirement of catalysts for bringing the virtual tendencies/ capacities associated with the physical material to reality brings the focus to Digital Twins, a term that has been doing the rounds as part of the Industrial Revolution 4.0. The research,

by taking cues from the already established theories and approaches, proposes MP 2.0 which augments the DFD strategy and integrates it with the Digital Twin technology to solve a part of the "Global Circular Economy" puzzle. “Material Strategies” by translating DFD strategies are established and the parameters associated with them while working across systems are depicted via a correlation matrix in the paper. A case scenario between two systems is shown to depict the complexity that arises when these parameters are interjected. Industrial Revolution 4.0 which is marked by CPS comes to aid this complexity. It requires cross-communication across machines and since the role of humans becomes secondary, data interoperability becomes the most crucial step for exchanging information across the systems. The research suggests JSON as a better alternative in comparison to XML for this purpose. It has proven to be computationally sustainable in handling and parsing complex data. In the process of establishing the parameters associated with “Material strategies”, the paper also highlights why the past attempts that either focus on BIM (the backbone of Digital twins) or GIS need integration. The research attempts to create a JSON prototype addressing all these findings. MP 2.0 which is ever evolving with new materials and information, not only the material circularity is restored but also the carbon emissions are reduced that are involved as a part of this exchange of materials across systems. It is an information and knowledge framework for urban ecology that extends the capability of an existing MP i.e., from a building to consider the earth as a mega building project. It envisions a transformed construction industry where the eternal essence of materials coexists within the transient urban ecosystem something which closely resembles the principle of nature where one system’s trash becomes feed for another.

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