Towards Sustainable Digital Transformation

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***Abstract*—Digital transformation is the form that IT development is taking nowadays that goes beyond digitizing information processing but includes a transformation of the organization, for instance new digital services or new business models. Digital transformation projects are therefore in a unique position to realize the sustainable development agenda.**

Sustainability is a major social concern of our times and has been addressed extensively in the IS literature. Current discussions on sustainability are mainly following the United Nations report, focusing on goals around energy consumption, carbon footprint reduction and the like. We believe that a broad discussion on two fronts is needed: (1) ensuring that the development and use of information systems is in line with sustainability objectives, and (2) ensuring that th organization doesn't falls back to the old 'steady state' after transformation initiatives are completed.

The first contribution of this paper is a holistic definition of sustainable digital transformation, based on an literature research. The second contribution is the development of a fractal sustainable object model and an exploration into the impact of this model on enterprise modeling in two small cases. The first case is about environmental accounting, the second on the enterprise engineering method. We consider this paper to be a first in a series. The focus is on developing the overall framework with some 'light weight' validation. A full verification and implementation is left for future research.

I. Introduction

Sustainability and digitization are big topics these days, both in academia, the business world, and government, as can be observed by looking at the daily news. These two trends provide the frame for this paper.

Consider sustainability. This term tends to put people in mind of 'green' or 'eco-friendly'. Certainly there is an abundance of reporting on floods, rising ocean levels, global warming, water pollution as a result of industrialization, and the turn towards electric vehicles. This is only the tip of the iceberg. Topics such as sustainability of food supply, health care (rising costs, availability of medication which in an area of– according to producers – may or may not be economically profitable anymore) and many other topics are discussed on a daily basis. The importance of sustainability as a topic is increasingly clear and has also made it to the management table. A good example is the recent move by BlackRock (the world largest investor, managing over $35tn in financial assets) to join a pressure group fighting reduction of emissions [1]. The topic is also increasingly connected to the realm of IT as a recent article in the Dutch newspaper *Financieel Dagblad* illustrates [2]. The title of the article translates to 'Digital Germany must be more sustainable'. The article explains that the German minster Svenja Schulze stated that, in 2025, digital systems "are likely to cause more greenhouse gas emissions than cars". In her opinion, internet giants such as Apple, Amazon and Netflix should take measures and help to ensure that "smartphones and tablets are more sustainable".

The other big topic is digital/digitization. Regarding this topic, we see a slew of articles on big data, cloud, artificial intelligence, digital twins and many others. These trends influence both our personal lives (domotica, the 'always on' mentality of the younger generation; privacy concerns) as well business strategy. It is safe to say that digital is the new normal (see e.g. [3]).

A. Sustainability

Sustainability is a big word with many meanings. Most people associate the term with 'green' or 'eco friendly'. This is also the common view in IT which tends to narrow the scope even further to power consumption and renewable hardware components (see e.g. [4] for a case about the sustainability strategy of Intel). The United Nations (UN) has a much broader definition which also includes reducing poverty, achieving gender equality, and improving education [5]. Some of these factors are definitely also relevant in IT settings. Still, we believe that the perspective is too narrow. We propose to adopt a definition of sustainability that not only covers the (already broad) UN perspective, but also includes the topic of *durability*, which aligns with the third meaning in the dictionary[1]:

> **Sustainable**: (1) able to be used without being completely used up or destroyed, (2) involving methods that do not completely use up or destroy natural resources, (3) able to at least continue for a long time.

The former two aspects closely align with the UN-goals around sustainability. The latter appears to be an underlying principle: things are said to be sustainable if they do not go away, if they are durable/ enduring towards the future.

B. Digitize/digitalize

An important distinction is made between *digitize* and *digitalize*. Borrowing from the work of Jeanne Ross [6], we define *digitize* as the process to replace traditional paper with

[1]Merriam-Webster's Advanced Learner's English Dictionary, 2017.

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a digital form (e.g. PDF) without adjusting processes much. On the other hand, *digitalize* is defined as a transformation of the enterprise where processes have been reinvented and redefined through disruptive technologies. In the digitalized space, the value proposition of the enterprise is often also affected, and becomes more data-driven/ enriched through the use of information services.

The 'real' introduction of computing started in WW2 and ever since, computing has been on the rise[2]. Initially used mainly by the military/ government, it quickly got adopted by businesses and later also for personal use. This adoption has its background in the developments of modern organizations confronted with a a complex and mass-scale (globalizing) environment. Bureaucratization and rationalization where the 20th century response to this challenge, with IT being the perfect technology. As such, this helped to sustain organizations, but where rationalization took the form of optimization of a small number of economic variables, it also lead to problems of its own. IT initially supported business, which gave rise to the challenge of strategic alignment [8], [9], whereas these days no meaningful distinction between business and IT can be made anymore: business *is* IT and vice versa [6], [10].

It appears that we have reached the point where society no longer blindly accepts further digitization. This becomes more apparent when considering the public debate on digital addiction, privacy, digital security, push-back against pervasive technology and the always-on-mentality that results from, among other things, push-notifications on the ever-present smartphone (see e.g. [11]–[15]). Organizations are struggling with the question of what to digitize and how, often in a highly competitive arena. These decisions include products and services that are offered to the public and the way they are serviced, but also how to leverage digitization best for the internal processes of the organization.

C. Research goal, setup, and contribution

In this paper we consider sustainability in the context of the increasing digitization of society. More specifically, the scope of our research is *sustainable IS*. Our overarching goal is to gain a deeper understanding of the decisions that organizations can make in light of sustainable IS goals and objectives, in all senses of the word *sustainable*. In this paper, we will use an approach based on design science to develop the initial version of a *sustainable design framework*. The framework is motivated (requirements) by an extensive literature study, and illustrated with two examples. This serves as a preliminary verification of the model. A full validation of the framework through industrial case studies will be part of future research (see e.g. [16] for an overview of design science).

This article is organized as follows. We will start with an extensive survey of the available literature on sustainable IS that sets the scope and provides requirements in Section II. III describes the framework and the two illustrative cases, followed by the Conclusion.

[2] [7] gives an interesting overview of break-through ideas in the development of computing.

II. Background

A. Sustainability dimensions

An important characteristic of sustainability research is that it aims to get rid of the mainstream narrow focus on economic profitability by including other criteria, in particular environmental and social. The new framework still includes the economic aspect [17], [18]. According to the former publication by Kiel, without *economic* profitability, any company loses its basis of existence. It aims at securing liquidity, productivity, and ROI. However, economic criteria can be more short-term directed (quick shareholders gain) or long-term. Sustainability implies a shift to long-term productivity and a broader stakeholder perspective (common good).

From an *ecological* point of view, companies act sustainable, if they consume just the resources that can be reproduced from living and non-living nature. Furthermore, [19] argues that they are expected to only produce emissions that can be absorbed naturally by the existing ecosystem. Both aspects determine a company's ecological and environmental performance. The authors present a framework that refines environmental criteria into secondary criteria such as energy consumption and waste production and tertiary criteria (e.g. direct and indirect energy consumption).

Social sustainability, according to Kiel, refers to company-specific actions that preserve and develop human and social capital of society, in which an enterprise operates to create value. According to Junker & Farzad [18], social sustainability is engaged with concepts of human existence, equal opportunities or participation. That this dimension is not easy to assess is demonstrated by the current discussions on AI in business: does it take away jobs, or does it create jobs? If there will be less work in the future, is that good or bad? Although the social sustainability criteria in [20] are written in such a way that they are easy to apply and measure in a company context, the system behind them is not very clear. Human rights are not mentioned as criteria directly, but hidden under "supply chain". There is no clear distinction between human criteria such as health and social ones such as equality. We would say that training hours (sustainability training) are not part of social sustainability; they are not a goal but a means that can contribute to all forms of sustainability.

The Framework for Strategic Sustainable Development (FSSD) has evolved over the years and applied in many settings [21]. Its focus is on natural environment and society/ people. The framework has formulated a number of principles and includes an operational procedure (ABCD) and starts with a systemic view of the domain under consideration. It is not possible to describe the FSSD framework here in detail, yet we will briefly mention highlights. This framework uses back casting. As a tool for forecasting, it "is not appropriate when planning for long term and novel goals in complex systems and when the dominating trends are themselves a main part of the problem" [21]. Back casting means that the strategic planning starts with developing a vision for the future that lies within the funnel of possibilities, but without letting the vision being constrained by the current situation. The next step is then to find a path from the present to this future horizon.

Other models and frameworks for sustainable, such as the GS3M method [22], characterize it according to five dimensions: not only economic, environmental and social, but also technical and individual dimensions are considered. *Technical sustainability* means that the artefacts, like software, can easily adapt to future changes. Quality attributes here include maintainability, portability and reusability, and durability. It is an accepted assumption in system theory that modularity lowers the need for coordinated changes, and hence contributes to flexibility [23]. Standardization also contributes to flexibility. *Individual sustainability* has to do with health, job satisfaction, knowledge development – in general, maintenance and growth of human capital.

The good thing about the GS3M model is that it goes broader but also deeper than the green or environmental concerns. Sustainable development has been defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [24]. Alternatively, it means that all resources, whether natural, artificial or human, are not only prompted to *realize their capabilities* (we intentionally use this formulation rather than 'exploitation', because in principle this is positive thing) but also *conserved* with the goal of maximizing their lifetime. A weakness of the model is that it has become so inclusive that it covers virtually all possible values, or value categories. The five sides of the GS3M model and their specializations are not really needed anymore when conservation of all involved resources is made a meta-requirement of all design, but can still serve as a checklist.

B. Green IT & Green IS

As IT is everywhere nowadays, different roles of IT/IS in sustainability must be distinguished. An important research area is green IT where the emphasis is on reducing the environmental impact of the IT itself (e.g. energy consumption of cloud providers) [25]. It is also called "green for IS". IT is a supportive function, and it can make significant contributions to mitigating the effects of global climate change and other environmental problems. This is the area of Green IS ("Green by IS") in which different subcategories can be distinguished [26]:

- IT as component of a sustainable artefact. Example: IT that is built into an Electric Vehicle for battery control.
- An IS whose primary goal is to *realize* sustainability. Example: a website that facilitates car pooling
- An IS whose primary goal is to *complement* a sustainable solution. Example an information system that optimizes the use of electric buses and their charging.

The distinction between the categories is not rigorous, yet it is useful for getting a better understanding of the role of IS in sustainability. The early paper of Seidel et al [27] is primarily about the second category, Green IS services, and uses a framework of *affordances* (action possibilities). The paper lists affordances such as *organizational sense making*, *dissemination of relevant information*, and *support of critical reflection and discussion*. These affordances are required to drive the realization of sustainable systems through e.g. *delocalization* (location independent work) and *optimizing work practices* such as zero-paper policies, or double sided printing.

Information dissemination is important as 'most companies still know very little about the potential environmental and social impact of their production networks' [28]. The possibilities of 3D printing, e.g. for spare parts, are a new kind of delocalization. The use of more accurate shipping information makes it possible for local shippers to make more use of ships rather than road traffic; this exemplifies a work practice transformation.

Hanelt et al. [26] call attention to the third category that they call, a bit ambiguously, *supporting IS*. The idea is that complementing eco-innovations with IS enhances their impact on organizational performance. The supporting/complementing role of IS seems to be special case of work practice transformation. However, a difference can be made between "greening" existing production processes on the one hand and supporting completely new eco-innovations, perhaps with new business models, on the other. For instance, an IS that contributes to the economic profitability of a green enterprise.

As there does not seem to be a difference between an IS supporting a green and a non-green innovation, all the known roles of IS can be relevant here, in particular to automate, inform and transform [29]. Efficiency impacts can be related to the role of *automation* (replacing human labour) as well as *information* (employees and management). Here, organizational savings (e.g. reduced overhead, lower resource consumption) are created through information technologies that reduce the need for human interaction (e.g. automatic data exchange) and improved information processing capabilities (e.g. increased planning accuracy). Supporting IS create value through increased connectivity among all resources required in the respective processes. Competitive [30] or innovative impacts are in turn related to IS' role of transformation, i.e. transforming existing business and industry processes and relationships, and coming up with new business models. Hanelt et al found that proactiveness of the IT stance (awareness of the power of IS and a positive attitude towards its use) is a critical success factor [26].

Hanelt et al are right in stressing the complementing role of IS in eco-innovations. In fact, there is almost no business innovation nowadays that does not involve IS. Their findings that indicate that supporting IS contribute to the success of eco-innovations are not surprising, in that respect. The title talks about 'driving business transformation toward sustainability'. However, there is nothing in the paper that shows that IS actually does drive business toward sustainability, as opposed to non-sustainable solutions, nor does it indicate how the former could be stimulated. It also does not touch the tough question whether, overall, the proliferation of IT in our society does lead to lower environmental impact, social inequality etc.

The work of Seidel and colleagues [27], [31] is more action-oriented and moves into the direction of design research.

A main conjecture of this green IS design theory is that the sustainability must be in the goals and not just a non-functional requirement. The theory uses the Belief-Action-Outcome framework. Belief formation has to do, for instance, with awareness of consequences. Action formation is about actions and include the above-mentioned sense making roles, but also e.g. the adoption of delocalized work practices. Outcomes are related to the consequences of actions, that is, environmentally sustainable work practices and environmentally sustainable decisions. All three formations can be described at a macro and microlevel. We think that a design framework is indeed important to realize sustainable IS, but we see it as unnecessary limitation of [31] to see Green IS as a subclass of information systems. Almost any kind of business transformation nowadays involves IS and thus involves an IS design phase. This IS design phase is probably the most suitable locus for translating the sustainability goals of the enterprise into practice. Hence, we need to 'green' IS design in general, rather than having a design method for a specific subclass only.

C. Value-sensitive design

Sustainability is introducing values and as we saw in the above, the more sustainability dimensions are included, the closer we get to value-based design in general. Sustainability is served by models and requirement engineering methods that take a broad view of values and a broad range of stakeholders. Winkler & Spiekerman provide an overview of models and methods that can help companies to figure out which values are important [32]. One of these, the model of Penzenstadler and Femmer consists of three layers [33]: on top the five sustainability dimensions, in the middle values (e.g. maintainability), value indicators (e.g. usage time) and value regulations; on the lower layer, activities that contribute to the values in the middle layer. Winkler & Spiekerman also list a dozen of important sources presenting values, such as the 12 principles of green engineering; value-sensitive design; and the ISO/IEC 25010 Product Quality model; in addition to general sustainable development documents such as the UN Millennium Declaration. From these sources, they extract an overview of values that are potentially relevant. The idea is that the overview can foster sustainable information system design and the discovery of new customer value propositions.

Friedman [34] and Van den Hoven [35], among others, have argued for value-sensitive design that aims at integrating (ethical) values in a systematic way into the design of technical artefacts. Latour [36] is famous for his statement that "technology is society made durable". Following this line of thinking, we delegate ethical rules to objects, for instance, with printing interfaces that prompt the user to think about the environment before printing.

The systematic approach of value-sensitive design consists of a conceptual investigation (into the values, and trade-offs to be made), the empirical (of the context of use) and the technical investigation (on the design of artefacts that support certain values). In [37] we have argued for a Transformational Design Research (TDR) method. In this method, design is a communicative act that responds to the past (problem analysis – empirical investigation) while anticipating possible futures (cf. the idea of back casting as discussed in Section II-A). At the same it explores the inter-subjective world of values (cf. conceptual investigation) and the outer world of physical reality and technology (cf. technical investigation). In TDR, both latter worlds need to be explored and transformed in designs that delegate values to technology.

In [37] a value expression method has been described. Following the value-sensitive design tradition, it assumes that technical development always includes value expression, but developers are not always aware of the values they express. The value expression method helps them to do it consciously and systematically. The proposed method builds on e3value modeling. Relevant to the current paper is that it distinguishes 3 levels: the individual, the exchange and the network. They can be related to sustainability. On the individual level, value is created by agents using their capabilities. A key sustainability goal is that for all agents to *protect* their capabilities (defensive) and to *realize* their capabilities (offensive). This level corresponds to the *individual* dimension of sustainability. Important to add here is that this goal can be generalized from agents to all resources, that is, both the technical resources (technical dimension) and the natural resources (*environmental* dimension). Sustainability means that also the capabilities of resources are both realized and protected. The second level of exchanges deals with the *economic* sustainability dimension (exchanges create economic value for both participants) but the exchanges also have an important social effect. Many social sustainability aspects, such as relationships, trust, accountability and dignity can be viewed as exchange qualities. Finally, the third level of the network considers the sustainability of the ecosystem: not only the economic viability (does the network provide positive value for all?) but also *social* sustainability, represented in values like justice, fairness and inclusion. Again, the objective is to realize and protect the capabilities of, in this case the ecosystem (whether it is the natural ecosystem, the social ecosystem, or the combination).

D. Life-cycle assessment

Life-cycle assessment has been one of the main pillars of sustainability studies, and is best known by the 'cradle to cradle analysis of products. The life cycle concept should be taken into account in any sustainable systems approach. However, the cyclical thinking goes deeper when grounding it in system theory. According to Kua [38], the *resilience* of a system can be defined as "the magnitude of disturbance/shock that can be absorbed before it changes to a radically different state as well as the capacity to self-organize and the capacity or adaptation to emerging circumstances". The *vulnerability* of a system can be understood as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of a shock". In general, vulnerability depends on three key factors—sensitivity, exposure, and adaptive capacity. Resilient systems will therefore contain cyclic adaptation processes (cyclic in the sense that they keep up some value or make the system return to the value if has been negatively affected). In the scope of this paper, it is not possible and also not necessary to go deeper into system theory, but we consider the cyclical process focus to be indispensable for any sustainable design approach.

LCAS (Life Cycle Assessment Systems) facilitate planning, implementation, and measurement of processes around waste management [39]. LCAS measures potential environmental, health, and safety impact caused by production byproducts such as toxic waste. It also enables measurement of broader environmental impact from energy use such as electricity and water, recyclable materials, use of fertilizers, greenhouse gas emission, etc..

E. *Holistic approach*

Based on our exploration of the literature on sustainability, we believe that sustainable development requires a holistic approach, for several reasons.

First, all sustainability dimensions have a goal and means element. Economic profitability, e.g. successful business models of ecological farming, can be seen as a means by which environmental goals can be achieved. Conversely, meeting the ecological criteria of reproducibility can be seen as a means by which long-term economic goals can be achieved. The same goal/means duality can be observed with social sustainability. Nowadays, innovative business models are often related to intensifying customer relationships. The necessity for a partner-like and trustful cooperation with customers, but also with suppliers relies on an open-minded corporate culture, which can only be achieved by involving top management coordinating and operationalizing interdisciplinary communication between intra-firm and inter-firm departments and stakeholders [17].

Second, it is often impossible to address all sustainability concerns for each process in the organization. Any production or transport process requires energy and usually consumes raw materials. Taking a broader scope makes it possible to compensate for losses in one process by gains in another. A third reason for avoiding to perform sustainability projects in isolation is the need for knowledge development in the enterprise [40], [41]. Finally, a fourth motivation for a holistic or integrated approach derives from the organizational hierarchy. According to ISO requirements, a sustainability policy is the responsibility of the top management, but the implementation is done on the work floor. At this level, predominantly operational measures are collected. There is a need to close the gap between policy and measures. Junker & Farzad have worked out a multidimensional target system on the three levels of IS planning (strategic, tactical, operative) which has been applied in an in-house logistics system [18].

F. *Key directions for Sustainable Process Management*

In order to identify key directions for Sustainable Process Management, we take the following definitions:

- An eco-system consists of resources that are dependent upon each other
- A resource is sustainable to the extent that it is protected against adverse effects and has an adaptive capacity over its lifetime. This applies both to the individual and the type level.
- A sustainable ecosystem is an ecosystem that is able to sustain itself and its resources over time (so the resources are sustainable and the system itself)

In the previous paragraph, we already concluded that a *holistic approach* should be followed for attaining objectives around sustainability. Furthermore, from the above definitions, we infer the following key directions for Sustainable Digital Transformation:

1) **Cyclical business processes**. Business processes are key players in Information Systems. Improving business processes has an impact on the enterprise performance on the one hand, while IT is one of the ingredients by which business processes can be improved, in terms of efficiency or quality. Redesign of business processes involves process modeling. Two types of process models can be distinguished: linear (workflow) models and cyclical (system) models. A *linear* model has a starting point/trigger and by going through several steps gets to an endpoint. The model can be complicated by including decomposition and orchestration. A *cyclical* model consists of one or more cycles or loops. From a sustainability perspective, linear process models must be avoided, not because a linear process is incorrect but it captures only part of a cycle. Typical example is a production process that starts from purchasing raw material and ends with products sales. To analyze the sustainability of this process, it must be extended to cover the whole product life cycle. Then it becomes clear whether such a cycle is viable in the long run, which extra activities must be included (e.g. waste return, refurbishing), and at which costs. It may also reveal hidden stakeholders.
2) **Resource invariants**. Cyclical processes must be analyzed from a sustainable resource perspective. Basically, it means that to be sustainable all resources seriously affected by the process do not diminish in value. Either they are kept stable or they increase in value. For instance, for a farmer involved in a milk production process, his monthly income must be sufficient for him to live (feed his household, keep his body in good health). Similar for the cows and for the pasture in which the cows are held.
3) **Cyclical coordination processes**. Large cycles like the product life cycle, or the top value cycle of an enterprise can be decomposed into elementary production steps where the transition from one step to the other involves a change of the agent. A transition is coordinated by an interaction cycle, such as modeled by the workflow loop in the Language/Action Perspective. For these cycles, it

has been argued that it is important to close the loop [42], [43]. An interaction needs to be based on commitment and needs to be finished not before the customer has expressed acceptance. It is possible to relate these goals to sustainability: closed loops build and maintain the social relationships; closed loops reduce the number of unfinished (wasteful) processes; closed loops support organizational learning.

4) **Protection by design**. Sustainability requires to view the environment not only as unstable but also as always potentially harmful. Any sustainable system therefore should somehow build a shell around it, a boundary with the environment that prevents harmful attacks as much as possible. Not all attacks can be anticipated of course. However, some obvious ones can recognized. Sustainability requires that protection is built into the design, and not added as an afterthought. An example is "privacy by design (citelangheinrich2001privacy. Protection by design can go beyond protection and also plan how the system could benefit from attacks (improve itself).
5) **Modularity**. Sustainability requires to view the environment as inherently unstable and unpredictable, and therefore views resilience as an essential design quality. The question is not *whether* disruptions will happen but how the system will respond to disruptions and survive. According to Simon's theory of near decomposability, complex systems with a modular structure tend to evolve and respond faster and are in the end more stable than systems with less independence between the parts. Modularity in IS is a well-researched topic. Modularity*by* IS means that the IS is used not only to connect different systems, but also as a protective interface.

Design involves making trade-offs between opposing forces. We mention the following:

1) **Reasonable completeness**. We mentioned the need to consider linear processes in the context of cyclic processes. More in general, from a sustainability perspective, IT designers and developers, should strive for maximum coverage. One important case is the completeness of the stakeholder analysis. A business case can appear to be positive only because certain stakeholders and their values are not considered. A major cause of unsustainable solutions is that the solution (and its model in the design phase) is too limited in scope. However, it also has to be acknowledged that completeness is often an illusion, because of the complexity and connectivity of the system in question and because of the bounded rationality of the designer [44]. Therefore, sustainability requires reasonable completeness. What is reasonable cannot be specified a priori but is learned in a community over time and typically materializes in check lists and standards.
2) **Value conflict**. When all stakeholders are included, often the value gain of one party goes at the expense of a value loss at another party. Sustainable design does not mean that only win-win situations are acceptable, but it does mean that at least value conflicts are made explicit rather than camouflaged. To address value conflicts properly, values of the ecosystem or community must be made explicit, such as fairness.
3) **Integration conflict**. The paradox of integration is that often efficiency gains can be achieved by integrating systems or more information exchange. For instance, the more information a supplier has about the demands of his customers, the lower can be his inventory level, and the lower the related inefficiencies and risks of capital destruction. Last-mile city logistics can benefit from integrating the systems of different carriers, with a lower impact on the social and ecological city environment as a result. However, as stated in the above, loose coupling and modularity of components help to make them more sustainable, that is, more resilient. The challenge is to integrate systems in such a way that autonomy is preserved as much as possible, as in the Multi-Agent Systems approach.

III. A FRAMEWORK FOR SUSTAINABLE DESIGN

On the basis of the key directions, we propose a framework for sustainable design that can be used as reference model in digital transformation projects. The core of the framework is a fractal object model (Figure 1). We call this model 'fractal' because of (1) its visual representation, which has some resemblance to a fractal, and (2) the interplay between objects and their dependent objects as will be explained shortly, and (3) the intricate interplay between object types, their lifecycle phases, and the (potentially changing) goals in these phases. The sustainable object in this model can be an artefact (IS artefact, material artefact, or a hybrid) but as the design must take care of the sustainability of all resources, we extend it to human beings, institutions and natural resources. The model combines the following essential elements: (a) objects/artifacts are considered in all phases of their life (life cycle processes), (b) actions executed in each phase are viewed from a MAPE control cycle perspective, to ensure that all actions are monitored and analyzed (or at least considered for monitoring) and the intention/ planning of each action is included, as this is more critical than the execution; note that the model does not specify who is doing the monitoring, so a centralized system is not the only option (c) dependencies between objects are explicated (hence a fractal model), and (d) sustainability goals are defined and evaluated on the basis of measurable indicators.

As digital transformation includes artifacts by definition, we suggest to start there. Artefacts have a make and use phase and have the property that they can evolve over time, by changes in the make phase or use phase. In each phase, the artefact relates to other objects, including natural resources and humans. Their sustainability must be specified as well. This may lead to an infinite regress. However, we envision a situation that the sustainability goals and performance metrics

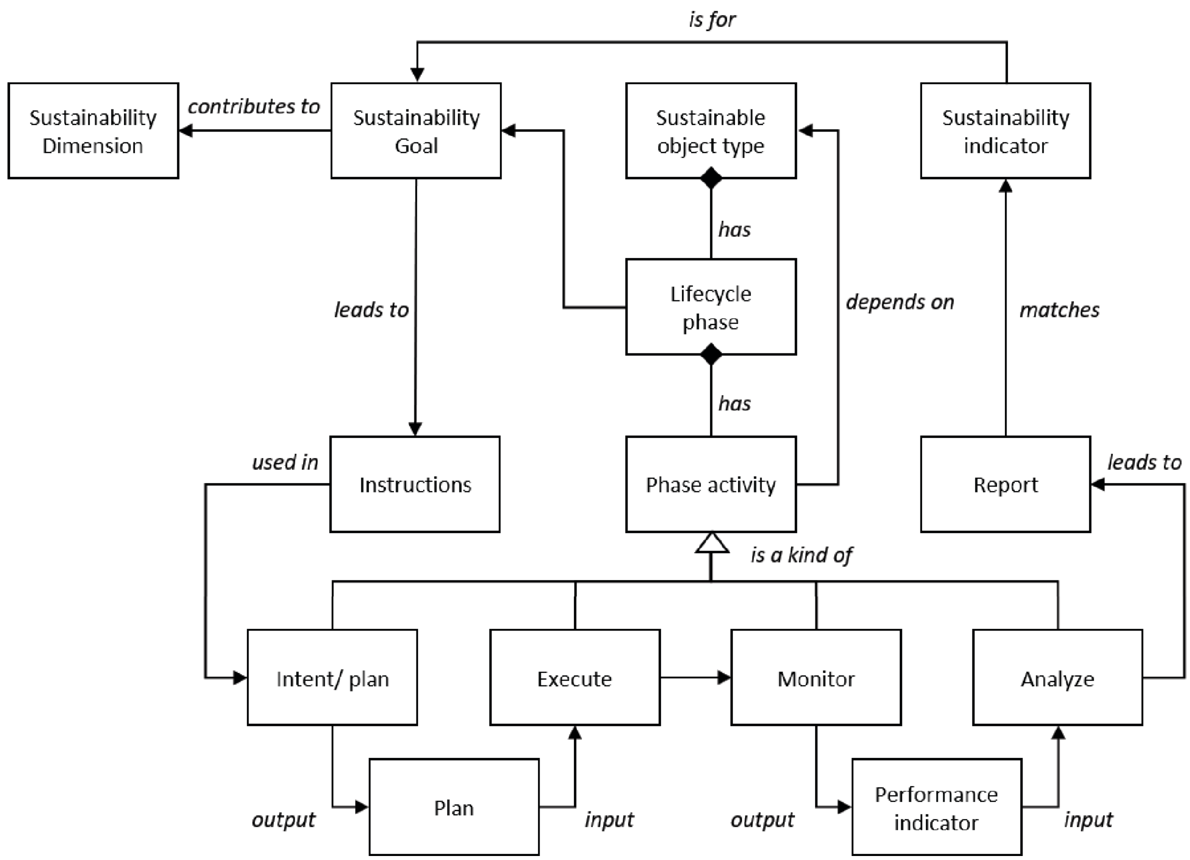

Fig. 1. The Fractal sustainability design model

of many resources can be inherited from public specifications (guidelines) and do not need to be worked out further.

As an example, consider an electronic vehicle (EV)[3]. Phases in the life cycle of the EV are design, manufacturing, transport, use, maintenance, and disposal. An ecological sustainability goal during manufacturing is that the amount of material used is not above some level, related to the amount of material that can be recaptured during disposal. Another goal is that the factory runs on renewable energy sources.On the economic dimension, the production costs is bound to a maximum, related to the reasonable market price.

During the actual production of EV instances, there is a monitoring activity that measures the amount of material used and other indicators. The aggregated data over a collection of instances in some period contributes to the sustainability indicator. In a similar way, also the transport phase, the use phase and all phases can be worked out. For instance, the length of the use phase (life time). One action in the use phase is the charging; the summed up charging has an impact on the power infrastructure. So the sustainability of this infrastructure is to be considered as well. The fractal property of the model comes into the picture when we consider the dependent objects. These can be either other artefacts (such as the built-in software or the tires of the EV) or affected resources (such as materials, or the social environment of the factory or the EV driver). For materials, the life cycle phases may include mining, use in production, being part of the car, maintenance, removal from car, disposal. A monitor activity in the use phase of material could be performed by IoT sensors, where the metric is the degree of aging, whereas a sustain goal can specify a minimum use lifetime (also relevant for the maintenance). For the social environment, assuming it is seriously affected by the EV factory, at least potentially, activities can include community building activities, whereas in the performance phase, the actual social events can be monitored. Note that a sustainability view of the social environment goes beyond the question of how to satisfy the stakeholder requirements of the neighbours: the goal is to protect the community and support its development. For both the material and the social environment, aggregated data are pushed up to the EV-artefact level.

The example can be extended to the electronic bus case used in [27]. Then, not only the EV itself is relevant, but also the passengers and their movements. The action of taking a bus is based on an intention that itself is influenced by the motivating

[3]We deliberately use a non-IT example here as several of the aspects that we want to discuss are more easily explained with a 'tangible' asset such as an EV.

information they get (instructions, in the model), as well as practical information (time schedule) that is supplied by IS artefact that they use. This becomes a separate artefact that is used in the use phase of the electronic bus (with a dependency relationship). Designing an IS on the basis of information requirements is not revolutionary of course. What is new is the overarching sustainability goal. As the example makes clear, supporting sustainability in a holistic way is quite a challenge. There is evidently need for the "reasonable completeness" principle, and to include expertise from multiple disciplines. The fractal model is an instrument to add sustainability to the models within the scope and to be explicit about the scope boundaries.

A. Enterprise Engineering

Many business process modeling approaches do not include the resource use or only as an optional part. If it is included, then in most approaches that we are aware of, the life cycle of the resources is not modeled. For a sustainable IS, we claim that the resource use and the resource life cycle should be made explicit. This does cost extra modeling effort, but helps to consider sustainability needs and take these into account in the design. Including resource life cycles can also increase the quality of the modeling itself. For one example, we consider Enterprise Engineering [45], in particular the Interaction Diagram (Actor Transaction diagram). An example is given in Figure 2 which represents an abstract model for a pizzeria. Transactions are modeled as diamond/circle, for instance, completion. One transaction stands for a complete workflow loop of initiation and evaluation, of which we stated in the above that closing the loop supports sustainability. The resources, notably the pizza, are missing from the diagram. In the Enterprise Engineering approach, the pizza object will be included in the State mode (Object Fact Diagram)[4]. The actions included (complete, pay, bake, deliver) are all lifetime events of either the pizza object or the exchange as object. The model would be stronger if the object life cycle is made into a modeling requirement. Then also the logic behind the actions (that completion requires baking, that baking is before delivery) would become visible, as well as apparently missing actions, such as the eating and the waste disposal. It is true that the latter actions are not in the scope of the pizzeria, but it is also true that they are, or should be in the scope of the pizzeria concern.

The life cycle of the objects can be modeled in different ways, e.g. the traditional Jackson Object Life Cycle Model . The Actor Transaction diagram does not have to *include* these, but a synchronization rule may be added that requires the actions in the Transcactions to refer to a life cycle action. Some actions combine multiple objects (e.g. wrapping (pizza and pizza box)) and so occur in multiple life cycle models. A converse synchronization rule requires that the life cycle actions are referred to in the Interaction Model. In the example,

[4]In other words, the model elements *are* part of the integral model, they are just not shown in this diagram type.

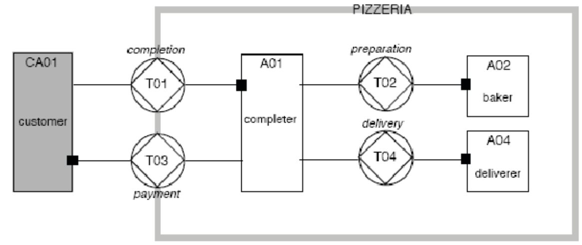

Fig. 2. Enterprise Engineering Interaction Diagram - pizza example

this would require an extension of Figure 2 to include an 'Eater Actor' that is connected to the Customer by a 'feed' transaction. The Eater and Customer may be the same subject, or not. Monitoring of this eating event, by means of customer reviews, can help to develop and improve the pizza object. The same interplay is also present in the realm of information systems, where code and modules are used and reused across programs. Managing the life cycle of these reusable objects is a known (software) engineering challenge. The pizza is not the only object. Monitoring and protection must also be applied to the human subjects. This includes the identification of risks, such as oven temperature for the baker or traffic accidents for the deliverer. A sustainable IS would include the collection of incidents and a systematic traceable way of handling these, and checking the compliance to safety norms. This would implement the Plan-Act-Check-Analyse cycle of the Fractal Object Model for these human subjects.

B. IS redevelopment

In this section we discuss an example that is amalgamation of cases from our experience in consultancy assignments.

Reuse has been a driver in the field of software engineering/ information systems development for years. Reusing code at the level of functions, classes, and modules was a first attempt, and reusing running code through services. Still, we end up with systems that need to be replaced at some point. Regretfully, rip-and-replace is still more common and more expensive than you would think (see e.g. [46]).

From a sustainability point of view, this means several things. First, the old code will no longer be after the rip-and-replace. The effort that went in developing and maintaining this system will be 'destroyed'. As such, this intervention is destructive. True: if the system was developed by a vendor (e.g. an ERP system) then the system will live on in other organizations, but from the perspective of the organization where it was running, the effort will be lost.

Assume the system is re-built in house. This raises a second level of discussion with regard to sustainability. First of all, there is the matter of the knowledge, time, and skills of developing such a system ourselves. A question that more and more organizations ask themselves is: do we really need to have the capability to do this, or can we outsource this to external parties? Outsourcing would mean that a lot of the knowledge that goes into developing such a system will be lost to the organization (unless additional effort is made). On the other end, developing the systems in-house would put valuable resources away from other projects which may hamper business outcomes as well as sustainability goals. This appears to be a catch 22. Resolving this tension is far from easy. A frequently heard argument is that staff that was maintaining the old system can be pulled into developing the new one. This argument simply does not hold, since the old system has to be kept up and running at least until the new system is live and has fully replaced the old one.

When the system is live, we move to a new life cycle phase. During the *operational* phase, new challenges arise. Let's assume the sustainability goals are still valid. Requests for new functionality will be coming in. Not just four 'our' system, also for others so there is a competition for scarce resources. Under the decision making stress, many organizations will choose new functionality over investing in maintenance, and will choose quick-fixes (band-aid) over structural solutions in line with the (sustainable) architecture of the system. This is how technical debt is born [47] and sustainability goals are hampered further.

It is our observation that these challenges occur because the immediate concerns receive more weight than the (long term) effects on sustainability, across the different life cycles. Zooming out even more, we believe that the life cycles of different systems can be linked from a sustainability perspective. One could argue that the lessons learned from developing and operating one system, including the end-user knowledge and skills about using that system, sets the stage for a more successful implementation of the new system. This would be a positive effect on attaining the overall sustainability goals of the organization. How to measure these effect is a matter of future debate, however.

C. Discussion

The two examples demonstrate how sustainability thinking can be brought into the design of Information Systems, illustrating the principles of cyclical business processes, resource invariants, cyclic coordination cycles and protection by design. As an initial evalution, we compare it with Recker's design theory for green IS [48]. One difference is that, as we argued, green IS should not viewed as a niche category. Sustainability should be addressed in all IS design. Still, there are many commonalities. Recker draws on affordance theory and the Belief-Action-Outcome framework. The latter corresponds to the MAPE cycle in which we embed actions. Beliefs are not modelled directly in our model, but belief *formation* is done by the Instruction that has a link to Planning/Intention. Both activities can be supported by tools (related to the artefact by a dependence relationship).

Tools can also be used in action formation - action in our model - for instance, the use of virtual workplaces to replace physical traveling. Outcomes in [48] describe what the consequences of the actions are. In the Belief-Action-Outcome framework this is also described as the functioning of the organization. In the fractal model, the practices are distinguished from the performance indicator. The latter are monitored. Affordance theory is deemed very relevant in [48]. First because it talks about user goals and abilities, as different from the artifact capability. The goals and abilities are accounted for in the fractal model, as the sustainability goals of the actor and the action possibilities, respectively. Secondly, affordance theory stresses that technological artefacts must have a material property, from which the affordance emerges, and a suitable symbolic expression. This seems to be a rather specific HCI requirement that does not belong in a sustainability model. However, we agree that an artefact is more than a material object. It has a specification that is embedded in a conversation between designer and user. Although we recognize the usefulness of Affordance theory and the Belief-Action-Outcome framework, and account for them in our model to some extent, we also claim that this theory is too general. It does not go into what makes sustainable design different from normal IS design.

IV. Conclusion

The observation that *sustainability* and *digital transformation* are key trends in society form the premise of this paper. Our overarching goals is to gain a deeper understanding of the decisions that organizations can make in light of sustainable IS goals and objectives. In this paper, we have adopted a *design science* approach [16]. We have presented an extensive survey of the literature on sustainability in this digital transformation space. We have used this to develop a fractal (reference) model for sustainability, and have illustrated this model through two examples. These examples serve as an initial verification of the model. The next steps of our research are to extend this verification, and to start a full validation through interviews and case studies. For this validation, we intend to develop a checklist, based on this model, to assess the degree of sustainability of the organizations information systems landscape. We are starting the discussion on case studies in three industries: logistics, sustainable energy, and finance. Ultimately, a validated model could lead to checklists and other tools that help organizations to attain their sustainability goals.

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