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Projecting a Complex IT Legacy Landscape onto Future Strategic Scenarios in the High-Tech Manufacturing Industry in Capital Goods

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Abstract. The high-tech manufacturing industry in capital goods is facing an increased competition landscape with shorter product life cycles, higher levels of mass-customization, and higher pressures on product delivery times. At the same time new IT developments for business growth are emerging, such as dynamic, inter-organizational supply chain information systems. Consequently, the concept of strategic flexibility has been growing in importance. However, historically concepts like lean and six sigma have been dominant within the high-tech manufacturing industry in capital goods and as such its information systems mainly support efficiency on an operational level. This results in a historically grown IT legacy landscape that has become too complex to handle strategic changes, meaning years and millions of Euros of investment required. In this paper, we propose a new design framework for aligning a business and information system architecture to help these companies regain insight in how to move from a complex legacy situation to achieving strategic advantage. This method contributes to existing research by explicitly acknowledging the reality of dealing with an imperfect IT legacy landscape in a fast-changing business context.

Keywords: Information systems architecture, IT legacy, Business-IT alignment, Manufacturing, Capital goods, Design framework.

1. Introduction

Researchers and practitioners agree that it is paramount for a company nowadays to be able to successfully utilize strategic business & IT developments to survive. This is consistent with a shift already announced in the 1990s [6] from IT used solely for efficiency to IT used for business growth. This shift has now reached the more traditional industries such as the high-tech manufacturing industry in capital goods as well.

The high-tech manufacturing industry in capital goods is facing an increased competition landscape with shorter product life cycles, higher levels of mass-customization, and higher pressures on product delivery times. Mass-customization requires an increase in flexibility of cooperation within and between supply chains as differences in demand may ask for different supply chain partners. As such, logistic processes like outsourcing have become increasingly more dynamic and complex [12]. In addition, shorter product life cycles and higher pressures on product delivery times imply a need for speed. As a result, new business developments like the creation of dynamic supply chain networks that enable a fast, inter-organizational integration throughout and between supply chains [9] have become key requirements. At the same time, new IT developments are pushing companies to start thinking about new possible functionalities. For example, within the automotive industry mechanical innovations are no longer the key for success, as automotive manufacturing becomes an increasingly digital environment, e.g. adjust driving dynamics like sport or comfort modes [14]. As a result, the ability of a company to integrate and coordinate its digital data within its boundaries and throughout its supply chain has become the new challenge. For example, within the automotive industry a company like Google already got ahead in the connected vehicle market [14]. To summarize, there is an increased necessity to achieve strategic business-IT alignment (BITA).

Losing insight into the structure of the current enterprise information system (EIS) architecture is a typical problem encountered in the high-tech manufacturing industry in capital goods and causes an increased difficulty in applying the strategic changes necessary [4]. In the short-term, years and millions of Euros of investment will have to be incurred due to ineffectiveness and inefficiencies when attempting to apply business changes to be supported by IT. On the long-term however, a more serious threat of inflexibility...
on the company’s strategic level can occur. To conclude, companies within the high-tech manufacturing industry in capital goods need to regain insight in how to move from a complex IT legacy landscape to a successful implementation of business & IT developments to gain a strategic advantage.

In this study we propose a dynamic business-IT alignment design framework, named DDBITA (Design Dynamic Business-IT Alignment), designed using the Design Science Research (DSR) paradigm [7]. This design framework provides the necessary context for a specific design process within a company to (re)structure its EIS architecture. It is an extension of an existing BITA framework [11] to explicitly acknowledge the reality of dealing with an imperfect, complex IT legacy landscape in the specific design process.

Section 2 provides an overview of related work; first discussing design frameworks and BITA frameworks for EIS architectures and second summarizing the latest business & IT developments within supply chain management. Next, Section 3 elaborates on the problem at hand by using a case study within the high-tech manufacturing industry in capital goods. In Section 4, the DDBITA framework is defined. Section 5 discusses the implementation of the DDBITA framework within the case study. Finally, Section 6 provides the conclusions and future research directions.

2. Related Work

An EIS architecture is defined as the structure or blueprint of information systems (ISs) that support business functions or processes within an organization [4]. Two faces exist of an architecture, the product-oriented face and the process-oriented face [4]. In this study the focus is on the process-oriented face, i.e. the design of EIS architectures. First, we discuss design frameworks for EIS architectures and BITA frameworks that are used as a basis for design frameworks for EIS architectures. Second, the latest business & IT developments in supply chain management relevant for the high-tech manufacturing industry in capital goods are summarized.

A design framework describes the context of a design process [4]. One well-known design framework is the Zachman framework [16]. Within the Zachman framework, two dimensions are defined, i.e. stakeholder perspectives as a vertical dimension and different design aspects as a horizontal dimension. The stakeholder perspectives support the design process by thinking about the architecture’s audience. The five perspectives defined are (1) the executive perspective, (2) the business management perspective, (3) the architect perspective, (4) the engineer perspective, and (5) the technician perspective. For example, an executive may be more interested in a list of process types supported by IT, while a technician requires a more detailed overview of the process configuration. Note that this dimension can be translated to BITA as a scale running from very business-oriented perspectives to very technology-oriented perspectives. The different design aspects support the design process by explicitly taking into account different types of viewpoints of an architecture, i.e. What, How, Where, Who, When, and Why. For example, for a supply chain information system (SCIS) the WHERE or location aspect may be important to visualize as this aspect provides relevant information about the different supply chain partners involved. However, the Zachman framework does not prescribe how to deal with a complex IT legacy landscape.

A different design framework is the three-dimensional design cube [4][8]. The cube provides a design space for a specific design process to traverse using three dimensions, i.e. aggregation, abstraction, and realization. As such, an EIS architecture can be positioned at one cell within the cube, depending on its level per dimension. Aggregation is defined as the level of detail. For example, an architecture may show the use of an SCIS module. If more detail is required, one level down the aggregation dimension this SCIS module can be “opened” to show a supplier relationship management (SRM) and a customer relationship management (CRM) module. Abstraction is defined as the level of concretization. For example, an architecture showing a SCIS module may provide limited information for a company that wants to buy such a module. One level down the abstraction dimension, an architecture may show the vendor of the SCIS module as additional information required. The realization dimension follows the BOAT-framework [4][8]. BOAT represents respectively a (B)usiness, (O)rganization, (A)rchitecture, and (T)echnology description of an architecture. Hereby, the A takes a pivotal position between B&O on the one hand and T on the other. Translated to a company within the high-tech manufacturing industry in capital goods, the B&O
perspectives represent the WHY and HOW of manufacturing the final product, the T perspective represents the WHAT in terms of IT, and the A perspective shows HOW the existing IT supports the manufacturing of the final product. Note that the realization dimension following the BOAT-framework can be translated to BITA. In addition, the aggregation and abstraction dimension aid in the definition of a complex IT legacy landscape. The three-dimensional design cube is similar to the enterprise modelling standard ISO 19439 in its use of cells to position a model. However, the standard ISO 19439 does not have a dimension that can be translated to BITA.

Another design framework that explicitly acknowledges the importance of BITA is SEAM (Systematic Enterprise Architecture Methods) [15]. SEAM proposes a hierarchy of systems by defining three different types of views that range from business-oriented to IT-oriented, respectively the service view, the supplier value network view, and the company view. However, SEAM is more focused on enterprise modeling than architectural design. In addition, SEAM does not acknowledge the reality of dealing with a complex IT legacy landscape.

A BITA framework supports organizations to maximize the business value of IT and has therefore been proven valuable to use as the basis for a design framework [2]. The most well-known BITA framework is the Strategic Alignment Model (SAM) [6]. This model emphasizes four dominant BITA perspectives a company can take in the design of an EIS architecture. Which perspective to take depends on the choice of wanting to achieve a strategic fit on the business-side or on the IT-side, as well as on the choice of wanting to achieve functional integration on the external (strategic) or on the internal (operational) domain. An interesting extension of SAM is E-SAM [3]. E-SAM states that SAM only describes how to achieve a top-down, strategic, BITA. Therefore, E-SAM proposes an extension of SAM to address issues of alignment on an operational level as well. However, both SAM and E-SAM again do not explicitly acknowledge the existence of a less than perfect IT legacy landscape. In addition, the increased competition landscape forces companies within the high-tech manufacturing industry in capital goods to embrace concepts like strategic flexibility. In other words, nowadays ISs do not exist in a static environment [4]. This implies that BITA is not static, but dynamic.

The notion of dynamic BITA is relatively new within literature [2]. A comparison study of existing BITA frameworks concluded that the dynamic BITA framework (DBITA) of Maes et al. [11] is one of the few frameworks that takes into account the dynamic nature of organizations [2]. As such, dynamic BITA is defined here as “the continuous process, involving management and design sub-processes, of consciously and coherently interrelating all components of the business-IT relationship in order to contribute to the organization’s performance over time” [11, p.19]. In other words, the DBITA framework explicitly acknowledges the existence of an IT legacy landscape. Within the DBITA framework three horizontal levels and three vertical levels are defined [11]. The three horizontal levels are strategic, structural, and operational. The strategic level represents the external domain, concerning long-term requirements about scope, governance, and core capabilities. The structural and operational levels represent the internal domain of a business. The structural level concerns the designing and managing of the organizational structure in terms of an EIS architecture. On the operational level, short-term requirements about variables like processes and skills are decided upon. The three vertical levels are business, information and communication, and technology.

A company has to balance two forces; demand pulls and technology pushes [4]. Demand pulls reflect the changing internal and external environments of organizations. As mention in Section 1, within supply chain management these include business challenges like the complexity of dynamic outsourcing [12] and new business developments like the need to create dynamic supply chain management networks [9]. Technology pushes reflect the dramatic improvement of IT developments that can support these demand pulls. There are many studies that have discussed the latest IT developments in supply chain management relevant for the high-tech manufacturing of capital goods by using reference architectures. Reference architectures are architectures not tailored for a specific situation or company [4]. In recent research, the two most commonly referred to challenges within supply chain management systems are the required dynamic coupling of ISs between organizations [9][10] and the handling of huge amounts of heterogeneous, multi-source, and real-time data [5][17]. IT developments such as multi-agent systems [9], service-oriented architectures [10], and mobility technologies like Internet of Things (IoT) [5][17] have been extensively discussed.
The strategic advantage lies in the coupling of demand pulls with technology pushes in an EIS architecture. For example, Liang et al. [10] introduced a service-oriented manufacturing (SOM) architecture to enable competing on a “supply-chain-versus-supply-chain” basis by creating dynamic supply chain networks. SOM manifests itself by the integration of the product or service throughout the supply chain, meaning the customer partakes in the entire primary process and the central organization mutually supplies the product or service with its suppliers. Another example is provided by Zhang et al. [17], who proposed a reference architecture that supports the translation of real-time data to valuable knowledge throughout the entire product lifecycle. Hereby, knowledge from the middle of life (MOL), e.g. use and maintenance of a product by the customer, may be used to optimize the beginning of life (BOL), e.g. the design and manufacturing of the product within the supply chain.

It is noteworthy to mention that the discussed reference architectures assume a greenfield or simple IT legacy situation. In this study, the purpose is to enable companies dealing with a complex IT legacy landscape to couple the relevant demand pulls and technology pushes as proposed by the reference architectures and gain a strategic advantage.

3. Problem Analysis

Company X is a company within the high-tech manufacturing industry in capital goods that was used as a case study in this research study. Logistic concepts like lean and six sigma are key to keep the company’s primary process efficient. As such, the logistic processes are a strength of Company X. ISs support these logistic processes. However, extensions and updates within the IS landscape have not been fully documented nor fundamentally reviewed for some time. At the same time, the IS landscape has grown substantially.

As mentioned, losing insight into the structure of the current EIS architecture is a typical problem encountered in the high-tech manufacturing industry in capital goods. The root cause may be the fact that the design process of the EIS architecture is mainly bottom-up, operational, in nature. In other words, systems are being developed on an ad-hoc basis both within the IT department as well as by business users themselves. The latter is more widely known as the “Excel-syndrome”. To illustrate, an employee requires insight into three types of information. However, this information may be scattered in three different, disconnected, systems. Therefore, the employee creates an Excel sheet that couples the three information streams. Meanwhile, another employee from a different department may need the same information, but now combined with information from a fourth disconnected system. He decides to couple the tables in the first Excel sheet with information from the fourth disconnected system to build a second, IT-supported application. Multiply this scenario and the result is a complex IT landscape full of loosely coupled extensions that are historically grown.

Company X perceived that not having insight into such a complex IT legacy landscape results in an increased difficulty to apply business changes to be supported by IT. More time and effort is needed in the analysis of the IT legacy landscape before business changes can be applied. In addition, due to the IT landscape’s complexity there is an increased risk of unexpected negative consequences like IT rework requiring additional time and costs. To return to our illustration, imagine a business change is required including the replacement of the first Excel sheet. In the analysis however, the second IT-supported application created was not incorporated due to a lack of insight into these loosely coupled extensions. As such, the second employee may temporarily not be able to perform his work and additional rework may be required.

On the long-term, the implementation of strategic changes may even become more challenging for companies within the high-tech manufacturing industry in capital goods like Company X. For example, for the company to be able to partake in a dynamic supply chain network, the company may decide to integrate real-time supply chain information using the IT development IoT. However, if the IT legacy landscape is full of loosely coupled extensions as illustrated, the required coupling with external IT systems may require a complete renewal of the IT landscape. This implies a required investment of years and millions of Euros.
To conclude, to regain insight into a complex IT legacy landscape the design process of a company’s EIS architecture should incorporate both bottom-up (operational) and top-down (strategic) business & IT viewpoints [4]. The bottom-up (operational) viewpoints are reflected in the complex IT legacy landscape; the AS-IS EIS architecture. The top-down (strategic) viewpoints are the demand pulls and technology pushes combined and are reflected in the reference architectures discussed in related work (Section 2); the basis for possible TO-BE EIS architectures. Successful implementation of (parts or combinations of) these reference architectures is where the strategic advantage lies. For example, the successful implementation of the service-oriented manufacturing (SOM) architecture [10] may enable competing on a “supply-chain-versus-supply-chain” basis as it supports the creation of a network of companies. The concept of BITA aids in combining the business on the one hand and IT on the other within an EIS architecture. The problem remains of how to combine the two viewpoints in a specific design process. In other words, how to solve the strategic misalignment when dealing with a complex IT legacy situation. Figure 1 illustrates the problem analysis using the DBITA framework [11].

4. The Design Framework

The design framework we propose helps to explicitly acknowledge the reality of dealing with an imperfect, complex IT legacy landscape in trying to achieve strategic advantage using the latest business & IT developments. Based on the problem analysis, this means the design framework is required to provide a context for a specific design process that incorporates (1) the translation of strategic requirements from demand pulls and technology pushes to the possible TO-BE EIS architecture(s), and (2) the mapping of the possible TO-BE EIS architecture(s) to the AS-IS EIS architecture.

The DBITA framework [11] was taken as a basis due to its explicit acknowledgement of the existence of an IT legacy landscape. The Integrated Architecture Framework (IAF) of Cap Gemini was proposed by the authors of the DBITA framework [11] as an extension to provide the context for a specific design process. The same authors note however that the IAF framework fails to define proper design dimensions on a strategic level required for the translation of strategic requirements. In addition, the process of mapping the two (or more) different architectures is unstructured. Therefore, we propose the three-dimensional design cube as discussed in related work (Section 2) [4][8] to extend the DBITA framework [11]. The resulting DDBITA framework is visualized in Figure 2.
As shown in Figure 2, the proposed framework consists of two parts; (1) architectural design and (2) business-IT alignment. This is the first dimension to aid in the integration of architectural design and BITA when dealing with a complex IT legacy landscape.

On the left-hand side, there is the architectural design where the IT legacy landscape or AS-IS EIS architecture is required as input. Here the goal is to map the functionality of the system modules of the possible TO-BE EIS architectures or reference architectures to the functionality of the system modules of the AS-IS EIS architecture. To do so, the different architectures have to be positioned at the same cell. To illustrate, a SCIS module may exist in the AS-IS EIS architecture. However, in a possible TO-BE EIS architecture positioned one level down the aggregation dimension a SCIS module contains a supplier relationship management (SRM) and a customer relationship management (CRM) module. When the architectures are positioned at the same cell, the mapping may show that the AS-IS EIS architecture does not support the functionality of the SRM module. Finally, the mapping will result in the design of the TO-BE architectural design, supporting the achievement of a strategic advantage.

On the right-hand side of Figure 2, the concept of BITA is used to translate the strategic requirements from the future vision(s) to strategic design dimensions. The future vision reflects the demand pulls and technology pushes. These dimensions in turn form the criteria for the selection of possible TO-BE EIS architectures. The realization dimension, or BOAT-framework, is mapped to the horizontal dimension. The Architecture in BOAT is then equivalent with the DBITA framework’s central column, i.e. Information and Communication. This is consistent with A as pivot between B&O on the one hand and T on the other [4]. The left column, i.e. Business, is split into (B)usiness and (O)rganization of the BOAT-framework. Splitting up Business into B and O has the additional advantage of explicitly defining both external (B) as well as internal (O) requirements. The right column, i.e. Technology, is equivalent with the (T)echnology of the BOAT-framework. As a result, the design dimensions on the strategic level that were missing before, are now defined as the B-, O-, A-, and T-requirements.

Finally, note that the vertical dimension on the right-hand side (business-IT alignment) defining the three levels strategy, structure, and operations is related to the two dimensions abstraction and aggregation on the left-hand side (architectural design). To illustrate, a cell at the strategy level corresponds to a high abstraction and high aggregation level.

Within every cell of the DDBITA framework in Figure 2, a specific type of modelling language is applicable. The modelling language depends on the column of the realization dimension or BOAT-
framework, respectively business models (B), process models (O), component diagrams (A), and infrastructure diagrams (T) (Figure 2). For example, at the strategy level within the B-column a business model like the business model canvas can be applied. At the operational level within the O-column, a process model using the language BPMN is advised.

Finally note that there also exists a temporal dimension, i.e. moving from the AS-IS or legacy structure to a TO-BE EIS architecture based on a company’s future vision. This temporal dimension will be described in Section 5 as five specific design process steps.

5. Implementation and Evaluation

The implementation of the DDBITA framework in Company X as case study resulted in five specific design process steps, illustrated in Figure 3. Note that the scope was set at all systems supporting the logistic processes required for the primary process. These logistic processes include the planning of materials (e.g. supply chain planning, material requirements planning) and the scheduling and execution of materials and operations (e.g. warehousing, line feeding).

![Figure 3: Five Specific Design Process Steps](image)

First, the AS-IS EIS architecture or IT legacy landscape was defined and positioned on the dimensions of the three-dimensional cube. To retrieve all the necessary information, interviews were conducted both within the IT department as well as within the operational department. To take into account the possible "Excel-syndrome" consequences as mentioned in the problem analysis (Section 3), this included interviews with business users that have been developing Microsoft Office applications critical for the primary process. In the end, the inclusion of these non-IT supported but critical applications turned out to be necessary for a complete overview. The AS-IS EIS architecture was positioned at aggregation level 3 (main systems like the enterprise resource planning system “opened” to define subsytems like the material requirements planning system), abstraction level 1 (functional specification), and realization level 3 (system architecture). Especially the aggregation level was helpful in completing this first step, as it forced Company X to take a helicopter view.

Second, future visions within logistics applicable to Company X were retrieved via a workshop. The stakeholders included represented the IT, logistics, and production functions. This workshop resulted in a short list of ten future visions based on three criteria scored on a five-point scale; (1) likelihood of the future vision occurring within five years, (2) negative business impact if the future vision can not be supported, and (3) system impact if the future vision is to be supported by the complex IT legacy landscape. Based on
the highest overall score and within the scope of this study, one of these future visions was selected for further analysis. The workshop was perceived as useful. However, the relevant stakeholders perceived that the first criterion, likelihood of the future vision occurring within five years, was difficult to estimate. Also, note that in order to have a complete overview of how to move from Company X’s IT legacy landscape to an EIS architecture that enables strategic advantage, the other future visions are required for future analysis as well.

The future vision selected was a more flexible, transparent material planning process. To translate this future vision to strategic design dimensions or requirements, two viewpoints of the BOAT-framework were used. First, the (O)rganizational view resulted in requirements of flexible business process management paradigms [1] defined in terms of workflow patterns [13]. For example, the support of exception handling patterns is required to steer the production process on a more ad-hoc basis, meaning an increase of the material planning process’ flexibility. Second, the (A)rchitectural view resulted in requirements defined in terms of architectural styles and patterns that support process flexibility and information transparency [4]. For example, an object-oriented architectural pattern enables a synchronous coupling that is required between the production process and the material planning process to increase information transparency. Note that the B(usiness) and T(ecnology) viewpoints were left out of scope due to limited resources.

Third, the O- and A-requirements resulted in the selection of two reference architectures or possible TO-BE EIS architectures. These two architectures were also positioned on the DDBITA framework. The reference architectures selected were considered very relevant for the company. Note that reference architectures with a more broad logistic scope exist that may also be relevant. However, analysis of the other future visions on the short list is required before conclusions on these architectures as possible TO-BE EIS architectures can be drawn.

Fourth, the mapping of the selected possible TO-BE EIS architectures to the AS-IS EIS architecture was conducted via a GAP analysis. First, the selected possible TO-BE EIS architectures were positioned at the same cell as the AS-IS EIS architecture by traversing the necessary steps through the cells, for example one step up the aggregation dimension to move from aggregation level 4 to aggregation level 3. Second, the IS modules in both architectures and its interrelationships were mapped. This resulted in around forty implementation steps. These implementation steps were evaluated as clear and innovative. To illustrate with an example, a material planning schema system is used in the complex IT legacy landscape or AS-IS EIS architecture as input for the material planning requirements system to offset the material requirements. In the possible TO-BE EIS architecture a flexible business process management system is proposed to provide the same functionality but enabling an increased flexibility in the offsetting of materials. In other words, depending on the current production situation the chosen routing to offset the materials becomes adaptable. Therefore, one implementation step is to replace the material planning schema system by a flexible business process management system.

Finally, the fifth step was the design of the TO-BE EIS architecture to make the implementation steps visible. This substantively improved insight into Company X’s IT legacy landscape and the implementation steps required to reach the future vision.

To conclude, the proposed DDBITA framework was implemented successfully in the case study. The most important lesson learned of the implementation was that the complexity of the domain requires a framework like the proposed DDBITA framework. The implementation of the DDBITA framework triggered Company X to think about strategic advantage through the design of an EIS architecture, starting from its complex IT legacy landscape. As a result, initiatives like a “Logistic Think Tank” to continue the analysis and designing a “Logistic 2.0 Roadmap” to achieve strategic advantage have been set up within the case study.

6. Conclusion

Companies within the high-tech manufacturing industry in capital goods nowadays struggle to move from a complex IT legacy landscape to successfully utilizing business & IT developments and hereby gain a
strategic advantage. In this study, a design framework was proposed to support companies facing this issue, i.e. the DDBITA framework.

The DDBITA framework supports a design process incorporating both bottom-up (operational) and top-down (strategic) business & IT viewpoints. Hereby, the framework enriches existing literature. Within the case study, the most important insight for Company X was the realization that an EIS architecture not just supports efficiency, but can also enable strategic advantage. The implementation of the DDBITA framework improved insight into two domains. First, Company X regained insight into its IT legacy landscape, including the non-IT supported but critical applications. Second, the implementation steps defined for the future vision selected helped Company X to start designing a roadmap for its system landscape supporting logistics. The next step for the company is to finish the analysis of the future visions selected and hereby complete the roadmap.

Two critical notes are however required. First, the B- and T-requirements were not applied within the case study. This may have reduced the insight provided by the TO-BE models. Second, the term future was bounded to future scenarios relevant within approximately five years. This boundary may not be optimal. It is expected that setting a future boundary within the DDBITA framework is possible between two extremes, i.e. one year is too narrow while ten years is too broad. If the scope will be set too narrow the focus on a strategic level is expected to be lost. If the scope will be set too broad the availability of relevant reference models is expected to be too limited. As such, the selection of a relevant future boundary within these two extremes is case study-specific.

For future research, other case studies are required to prove the generalizability of the DDBITA framework. Note that up till now the scope has been the high-tech manufacturing industry in capital goods. A complex IT legacy situation may also be found in other, more service-oriented industries like the telecommunications industry. The focus of IT on supporting efficiency on an operational level can be related to the huge amounts of investments required to produce a product or service. Within a service-oriented industry, these required investments may be the employees providing the service. Two assumptions are necessary for the DDBITA framework to be generalizable to other industries as well. First, the alignment on an operational level was assumed workable within the case study. Second, relevant reference models have to be available. The latter assumption is more difficult to generalize and depends on the specific application domain.

7. References


