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BUSTECH 2023 Editors

Hanen Ochi, EFREI Lab Research, France

BUSTECH 2023

Forward

The Thirteenth International Conference on Business Intelligence and Technology (BUSTECH 2022), held on June 26 - 30, 2023, continued a series of events covering topics related to business process management and intelligence, integration and interoperability of different approaches, technology-oriented business solutions and specific features to be considered in business/technology development.

Similar to the previous edition, this event attracted excellent contributions and active participation from all over the world. We were very pleased to receive top quality contributions.

We take here the opportunity to warmly thank all the members of the BUSTECH 2023 technical program committee, as well as the numerous reviewers. The creation of such a high quality conference program would not have been possible without their involvement. We also kindly thank all the authors that dedicated much of their time and effort to contribute to BUSTECH 2023. We truly believe that, thanks to all these efforts, the final conference program consisted of top quality contributions.

Also, this event could not have been a reality without the support of many individuals, organizations and sponsors. We also gratefully thank the members of the BUSTECH 2023 organizing committee for their help in handling the logistics and for their work that made this professional meeting a success.

We hope BUSTECH 2023 was a successful international forum for the exchange of ideas and results between academia and industry and to promote further progress in the area of business intelligence and technology. We also hope that Barcelona provided a pleasant environment during the conference and everyone saved some time to enjoy this beautiful city.

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Supervised Classification with Deep Graph CNN

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***Abstract*—Convolution neural networks (CNNs) have performed remarkably well in recent decades and become essential for classification tasks based on images or voice. However, this paper addresses some of their limitations in terms of generalization and examines some well-known CNNs architectures that try to create hierarchical structures based on graph databases. The contribution of this work is to present a structure where the convolution blocks are distributed in nodes, the relations between each node being articulated using a data partitioner. This exponentially multiplies the number of models depending on the depth of the graph and the number of partitions, but it keeps track of the hierarchical relationships between each node.**

Keywords-convolution neural network; image processing; classification; neuronal network architecture; deep learning; incremental learning

I. Introduction

In recent decades, Convolutional Neural Networks (CNNs) have demonstrated remarkable performance and have become indispensable for image and voice classification tasks. However, as the field of deep learning continues to advance, it has become increasingly important to address the limitations of CNNs in terms of generalization and explore alternative approaches to overcome these challenges.
This paper aims to shed light on some of the inherent limitations of CNN architectures and examines existing CNN models that attempt to create hierarchical structures using graph databases. While these models have shown promise in capturing hierarchical relationships, they still face certain limitations in terms of scalability and flexibility. The paper is composed of a state of the art, contribution and experimentation.

II. Related works

The section on related work provides a comprehensive review of existing literature and research efforts focusing on CNN architectures, incremental learning, hierarchical classification, and approaches for improving explainability in deep learning models.

A. Symbolic representation vs Texture

Convolution neural networks (CNNs) [1] [2] can be thought of as filters whose role is to reveal the parts of an image that best identify the category it belongs to. One way to visualize how these filters operate is the GRAD-CAM technique [3], which draws a heatmap representing the areas of images that contribute most to their classification.

Figure 1 is a typical example of GRAD-CAM taken from [4]. This picture suggests that the model used ears and skin

Fig. 1. Example of GRAD-CAM

to correctly classify the picture as African elephants.

Figure 2 represents a set of cat images submitted to a VGG19 [5] architecture trained on ImageNet [5] allowing classification of images among 1000 categories. The pictures were enhanced using GRAD-CAM in order to highlight the most discriminating parts.

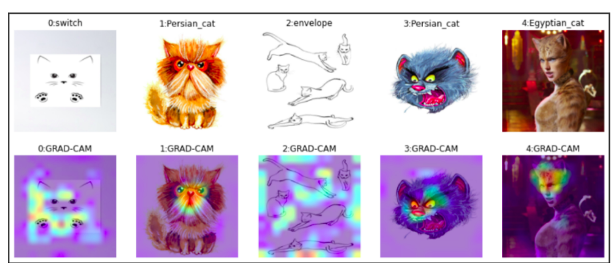

Fig. 2. Classification of cats

While some cats were correctly classified (the second, fourth and fifth image), others were not, and the GRAD-CAM helps to understand why. The model is myopic: it focuses on the hair texture of the cat which seems to be a better discriminant than the shape of an ear, eye, or tail. In the first

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and third image, we can see that the model has revealed what we as humans perceive to be background elements. The model relies on details, completely missing the main features likely captured in the first layers of the model. The accuracy of a prediction depends on the density of details in the pictures that are related to a specific category and not on the strength of the symbolic representation of the category, which is more related to the shape or the specific parts of the object to be classified. Intriguingly, the helicopter is not part of the 1000 categories while there are many detailed means of transport. Is this an oversight, or is it because the helicopter is a perfect example of an object with strong symbolic representation but a poor density of discriminatory details—having a propeller and a body with heterogeneous textures.

B. Prioritization and relationships

Figure 2 shows the result of the classification of pictures of humans.

Fig. 3. Classification of humans

Humans examining these pictures would immediately recognize members of the human race, while the model focuses on their clothing. Clothing might be an interesting way to classify humans, but there are many use cases when it is important to obtain some information on the person wearing them. This leads to a major concern about the model and how it was trained—the horizontality of the classification seems to have a serious limit. The model tries to differentiate objects, species of animals, and types of clothes on a unique level when classification is actually mostly hierarchical, as shown in Figure 4.

A tree is a good structure to represent a hierarchical classification but a graph will complete this one by defining the type of relation existing between categories as shown in Figure 5.

C. Stability on retraining

One of the recurring challenges in image classification, especially in medical classification tasks such as providing a diagnosis using medical imagery, is the stability of a model after successive training sessions [6]; the model is first trained for a task without having the whole spectrum of data and loses efficiency when images whose type is a little different from the initial domain are added. In medical fields, these differences, known as domain shift, may be due to the evolution of imaging techniques, the difference between brands, hospital practices, but also because of the difficulties in obtaining a dataset from

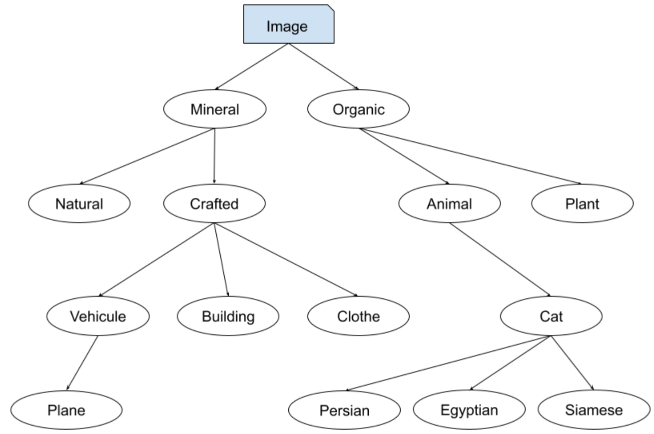

Fig. 4. Hierarchical classification

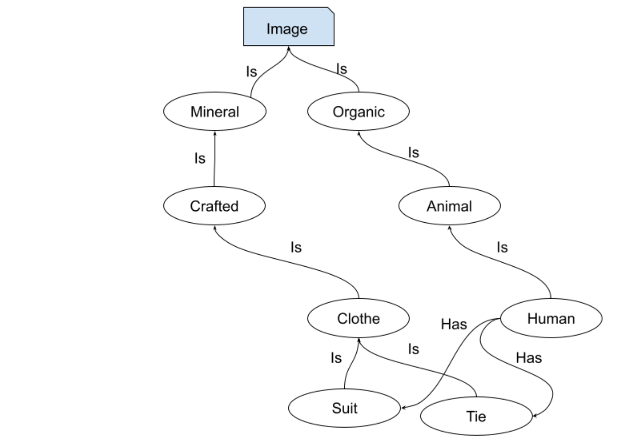

Fig. 5. Graph classification

several hospitals due to the private nature of the images. Another cause of the domain shift, is the medical condition (e.g., standing and conscious or lying down and unconscious) of a patient at the moment an image is taken, affecting the images quality and interpretability. Medical models tend to specialize in a specific dataset, and it is often difficult to increase the diversity of image sources without degrading the quality of predictions. Some techniques [10] and [11] try to attenuate the problem of stability, but this also raises the question of the pertinence of having one unique model handle a specific task. While humans can adapt their judgment according to context (an expert can recognize the specificity of a machine or a medical condition), why should a CNN model find a middle way in order to globally reduce its loss function?

D. Desconstructing a CNN

The examples above show that even if CNN can extract image features to an extraordinary extent, stacking convolutions blocks may focus on detail and texture, losing the broader

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picture. The use of a horizontal, flat categorization hides the hierarchical relationships between classes. Finally, a dataset can be composed of different contextual information even if the purpose (a diagnostic by example) is unique. Incorporating this diversity into a single model can cause its performance to drop as it tries to average the best solution among different cases. We believe that an evolution of classification tasks based on CNNs, should organize convolutional blocks into more complex structures, such as graph databases.

A CNN architecture can be summarized to a feature extractor whose output is flattened to feed a classifier. The feature extractor is a sequence of convolution blocks, which are an arrangement of convolution layers followed by a pooling layer, while the classifier is a fully connected neural network, as shown in Figure 6 . There are several architectures for convolution blocks that solve different problems like ResNet and Inception .

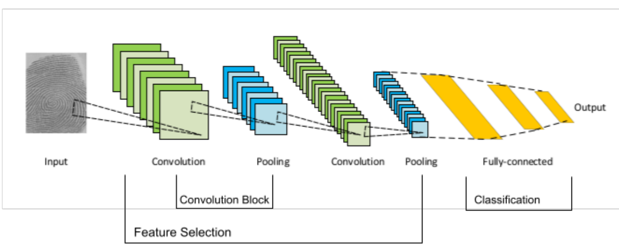

Fig. 6. CNN architecture (image taken from [7])

Related works are Tree-CNN [8], Growing Hierarchical Neural Network [9], [10] or Incrementally Growing CNN [11], which try to adapt CNN structures to the diversity of data and classified classes.

III. Contribution

The main contribution of this work is the introduction of a novel hierarchical structure where convolution blocks are distributed across nodes, with the relationships between each node orchestrated using a data partitioner. This architectural innovation exponentially increases the number of models based on the depth of the graph and the number of partitions, while still maintaining the hierarchical relationships between each node.

By distributing the convolution blocks in this manner, we create a more intricate and specialized model that is capable of capturing complex patterns and features across different levels of abstraction. The hierarchical organization allows for better representation of the underlying data structure and facilitates effective information flow throughout the hierarchical model.

A notable advantage of this distributed architecture is the sharing of loss function gradients among the common roots of the specialized models during training. This shared gradient propagation enhances the model's ability to collectively learn from the training data, leading to improved overall performance.

To provide a visual representation of this novel architecture, Figure 7 illustrates the general structure of the proposed model. It showcases the interconnected nodes, each housing specialized convolution blocks, and the data partitioner facilitating the flow of information and gradients between the nodes.

Through extensive experimentation, we evaluated the performance and efficacy of this distributed convolutional architecture on various benchmark datasets. The results demonstrate the potential of our approach to achieve enhanced accuracy and efficiency in tasks such as image recognition, natural language processing, and sensor data analysis.

In summary, our work presents a novel architectural structure where convolution blocks are distributed across nodes, connected through a data partitioner, and organized hierarchically. This approach leverages the benefits of specialization and shared gradient propagation, ultimately leading to improved performance and adaptability in deep learning tasks.

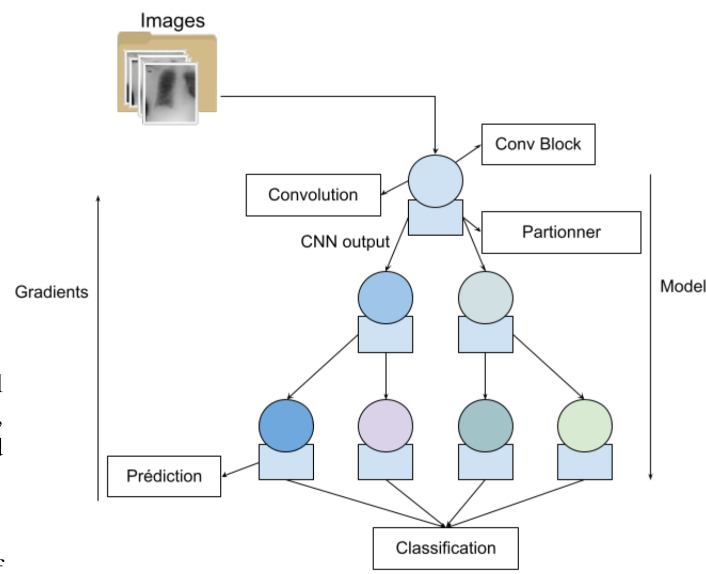

Fig. 7. Partitionned CNN architecture

IV. Experiments

To validate the effectiveness of our proposed approach, we conducted a series of experiments on various datasets spanning different domains. Our experimental setup aimed to assess the performance and robustness of the enhanced CNN architectures in real-world scenarios and on different aspects described as follows:

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A. Dividing data

We retained two approaches to split the data: similitude and intuition. Similitude divides data between entries that are similar when intuition divides data using a result of a prediction, and also the degree of confidence to that prediction.

Similitude: Similar images should be treated the same way. Evaluating similitude from an automated perspective can be achieved, through Intersection over Union, Cosine Similarity [12] but also by K-means [13]. Using K-means at a flattened output of a convolution block creates clusters of images presenting similarities. This can be used to divide the dataset, the number of clusters being determined arbitrarily or using the number of classes to be predicted.

Intuition: When a model predicts a class, it is making an assumption often using a softmax activation defining the probability of an input to belong to a specific class. The confidence in the assumption increases when the probability tends to one. Adding a fully-connected network at the output of a convolution block using a softmax activation for the last layer can be used to divide the dataset by assumption. The partition can use the degree of confidence of the model. One group contains images whose prediction has a really high degree of confidence, and other groups can be created based on classes, or just using the images with lower degree of confidence.

Tests: Using a problem of pneumonia detection realized during my internship at Delafontaine Hospital, St-Denis, based on chest x-ray, we trained a reference model based on ResNet50v2 [14] architecture trained on Imagenet coupled with a fully-connected network. The training dataset was then clusterized using K-means (K=2) at a flattened output on a ResNet50v2 (ImageNet) without any classification. Another clusterized dataset was created using the reference model dividing the dataset using intuition: one group contained images where softmax "probability" was higher than 0.98 while other contained all the other images. For each cluster, a model was trained separately with the same architecture and parameters as the reference model. Training each cluster separately produced different results in both division techniques as shown in Table I.

TABLE I
DATA CLUSTERING

Model	Training files	Testing files	Imbalance	Accuracy
Ref	6325	1581	0.29/0.71	0.86
Sim 1	5734	1432	0.23/0.77	0.80
Sim 2	593	147	0.93/0.07	0.95
Int 1	3499	874	0.16/0.84	1
Int 2	2827	706	0.46/0.54	0.74

The clustering by similitude created two groups and one of them contains almost exclusively negative cases, which is also a smaller dataset. It has isolated a specific type of image which is a clearly identifiable negative case (593*0.93 = 551). Clustering by intuition where confidence is high shows approximately the same number of images (0.16*3499 = 559) when considering negative cases. These sets of images are indeed the same which are x-rays taken in optimal condition when the patient is healthy, standing and conscious. The intuition cluster with lower confidence became more balanced. The validation scores show for that a high confidence is correlated with the accuracy and that the accuracy for images where confidence is lower reflects the capacity of the model to deal with gray areas which is an important information: a doctor want to know how the model is dealing with cases where he has doubts, not the easy cases. That correlation was confirmed by radiologists when evaluating manually the performances of our model. Splitting the data gave us the same average performance, but we gained in granularity for explainability. Future works will try to use different models, to see if it is possible to improve the average performance for the datasets containing more complicated cases.

B. Architecture

CNNs models have some limitations but they also have the great benefit of being simple, easy to maintain, obtaining great performances. At the opposite, partitioning the data and convolutions structure are complexifying the model, the training and the maintainability. Our first experiment is based on a unique model approach, trying to embrace the complexity step by step.

Unique model approach: we used the Keras library with its functional api to build a unique model having the shape of a tree. We used the VGG16 architecture as a template which is composed of 5 convolution blocks. Using a custom triage layer using a K-means model that splits the output and chaining convolutions blocks.At the end of the mode, a fully-connected network performs the prediction. Our model supports 5 levels of depths (1-5), adapting the first convolution block to recreate VGG16 architecture having K^{level} prediction models. Figure 8 presents the schema of a model with K=2 and a depth of 3 which generates 8 different VGG16 structures.

The structure of each model being the same as the VGG19, we can still use transfer learning [15] on each convolution block. The main challenge is that we have to concatenate then sort the predictions to be able to match each batch input order (partitionning the batch shuffles it). The first convolutions blocks are shared by their children. At each level the convolution blocks are specializing to a type of image. This kind of tree has a limited complexity and will be used in future works to analyze the pros and cons of using such a model.

Multiple models approach: if the unique model architecture lets us experiment with separate training between different categories of images, developing specialization at deeper levels and keeping track of the common grounds, it has a limited perspective of evolution. Triage layers will probably generate empty datasets, and some blocks won't be activated: the model is too static. An alternative approach will consider convolution blocs and data paritionners as entities. Each convolution block is trained separately and is chained to another block to a partitionner as shown in Figure 9.

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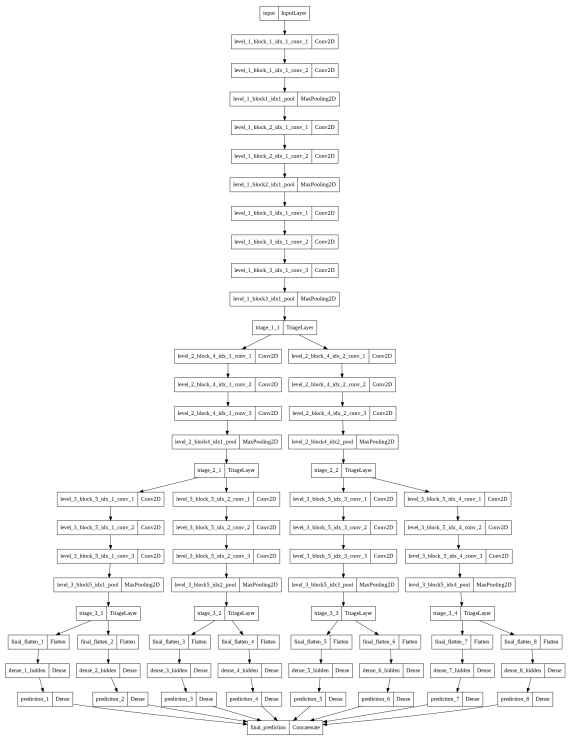

Fig. 8. Partitionned CNN architecture using Keras

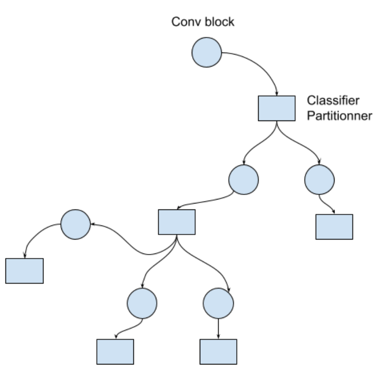

Fig. 9. CNN as as graph architecture

The structure of such an architecture can be represented as a graph and it will grow dynamically as follows: starting with a training dataset, a convolution block and a classifier, the model is trained until the loss function doesn't improve. Images proposed from the training set will have high confidence and the model will return prediction without having to change. When new images are proposed to the model and that confidence decreases, the model starts to partition and store the output data of the convolution block. When uncertain data reach a sufficient size, new convolution blocks are chained to the partitionner (according to the number of predicted classes) and trained using this new dataset.

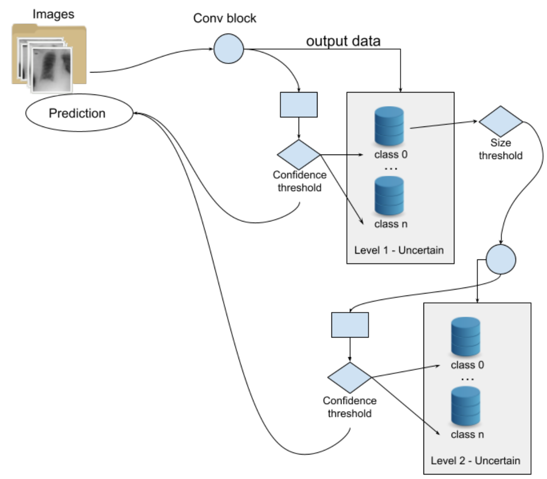

Fig. 10. CNN as as graph architecture

Figure 10 represents the data flow for training, growing and predicting with a graph CNN. The graph will grow as uncertainty samples presented to the model are increasing. New datasets are generated from output of convolution blocks only for images with low confidence. Images submitted for prediction will be treated by the first block. If the level of confidence is high enough the prediction will be returned, otherwise the output data will be forwarded to the next node if it exists or stored in the uncertain data database that will be later used to train a new child node. The uncertain data storage is necessary to be able to control data flow while training. It is a temporary data and can be deleted after training. We can consider it as a short term memory, while a trained node is considered as long term memory. Future works will try to build such a graph trying to solve different classification problems.

V. Conclusion

In this paper, our aim was to highlight certain limitations of current CNN architectures, specifically in the context of incremental learning and hierarchical classification. We put forth several ideas that revolve around data partitioning and chaining convolution blocks to address these limitations and enhance the explainability and specialization across diverse source types.

Our proposed approach, incorporating data partitioning and convolution blocks chaining, aims to overcome these challenges and improve the performance of CNNs in hierarchical classification tasks.

In summary, our paper emphasizes the limitations of current CNN architectures, particularly in the realms of incremental learning and hierarchical classification. We propose innovative ideas centered around data partitioning and convolution blocks chaining to enhance explainability and specialization across different source types. Our intention is to evaluate and refine these more complex structures through real-world use cases in future research efforts.

ACKNOWLEDGMENT

Thanks to Laurent Payen, head of radiology at Delafontaine Hospital, St-Denis, who helped me to understand the mechanism of interpretation of an image by a human expert.

REFERENCES

[1] Y. LeCun, L. Bottou, Y. Bengio, and P. Haffner, "Gradient-based learning applied to document recognition," in *Proceedings of the IEEE*, vol. 86, no. 11, 1998, pp. 2278–2324.

[2] A. Krizhevsky, I. Sutskever, and G. E. Hinton, "Imagenet classification with deep convolutional neural networks," in *Advances in Neural Information Processing Systems*, F. Pereira, C. Burges, L. Bottou, and K. Weinberger, Eds., vol. 25. Curran Associates, Inc., 2012.

[3] R. R. Selvaraju, M. Cogswell, A. Das, R. Vedantam, D. Parikh, and D. Batra, "Grad-cam: Visual explanations from deep networks via gradient-based localization," in *2017 IEEE International Conference on Computer Vision (ICCV)*, 2017, pp. 618–626.

[4] F. Chollet, *Deep Learning with Python*. Manning, Nov. 2017.

[5] K. Simonyan and A. Zisserman, "Very deep convolutional networks for large-scale image recognition," in *3rd International Conference on Learning Representations, ICLR 2015, San Diego, CA, USA, May 7-9, 2015, Conference Track Proceedings*, Y. Bengio and Y. LeCun, Eds., 2015.

[6] S. U. Rehman, S. Tu, O. U. Rehman, Y. Huang, C. M. S. Magurawalage, and C.-C. Chang, "Optimization of CNN through novel training strategy for visual classification problems," *Entropy (Basel)*, vol. 20, no. 4, Apr. 2018.

[7] S. Minaee, Y. Boykov, F. Porikli, A. Plaza, N. Kehtarnavaz, and D. Terzopoulos, "Image segmentation using deep learning: A survey," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 44, no. 7, pp. 3523–3542, 2022.

[8] D. Roy, P. Panda, and K. Roy, "Tree-cnn: A hierarchical deep convolutional neural network for incremental learning," *Neural Networks*, vol. 121, pp. 148–160, 2020.

[9] I. Mrazova and M. Kukacka, "Image classification with growing neural networks," *International Journal of Computer Theory and Engineering*, pp. 422–427, 01 2013.

[10] J. Herrero, A. Valencia, and J. Dopazo, "A hierarchical unsupervised growing neural network for clustering gene expression patterns," *Bioinformatics*, vol. 17, no. 2, pp. 126–136, Feb. 2001.

[11] D. Sam, N. Sajjan, R. Babu, and M. Srinivasan, "Divide and grow: Capturing huge diversity in crowd images with incrementally growing cnn," 06 2018, pp. 3618–3626.

[12] G. Abosamra and H. Oqaibi, "Using residual networks and cosine distance-based k-nn algorithm to recognize on-line signatures," *IEEE Access*, vol. 9, pp. 54 962–54 977, 2021.

[13] E. Ahn, A. Kumar, D. Feng, M. J. Fulham, and J. Kim, "Unsupervised feature learning with k-means and an ensemble of deep convolutional neural networks for medical image classification," *unpublished*, vol. abs/1906.03359, 2019.

[14] K. He, X. Zhang, S. Ren, and J. Sun, "Deep residual learning for image recognition," in *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, June 2016.

[15] M. A. Morid, A. Borjali, and G. Del Fiol, "A scoping review of transfer learning research on medical image analysis using imagenet," *Computers in biology and medicine*, vol. 128, p. 104115, 2021.

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Blockchain for Optimized Digital Identity (DIDOs)

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***Abstract*—The blockchain is a new and emerging technology that gives us the opportunity to explore a new type of application, and a new class of problem solving. Blockchain has acquired massive popularity over the past few years. It has changed the way of thinking about data and trust, and the relation between them. This work is a part of our publication's series aiming to build a data trust on top of a decentralized identity (DID) which we name Data Trust Protocol. In this article, we focus on the DID. We propose an implementation of a DID based on W3C specification, as well as our vision about the future of data trust on top of a DID. We will answer some questions related to this implementation.**

Keywords - Decentralized Identity; Issuer; Holder; Verifier; MicroServices; DID Document; BlockChain; Data Registry;

I. INTRODUCTION

In the last decade, with the exploding number of applications that we use on a daily basis, we mostly use an email or a username or a key provided by organizations or services as our identifiers. Those providers become a single point of failure between users and every action they made which needs authentication. Google and Apple control two of the biggest federated login systems with "Login width" button. Users expose their identity details in a centralized manner with a major risk of identity theft, identity usurpation. The problem has become more apparent and centralized. The need for a new way to identify people and objects becomes more urgent with the development of the Internet of Things (IoT). IoT is defined as "An infrastructure of interconnected objects, people, systems and information resources together with intelligent services to allow them to process information of the physical and the virtual world and react" [1]. Every day we add a new connected object to our life starting from our new vision to define the place where we live: smart cities, parking management, energy management, personal health, and safety, remotely checking patient health. We even define agriculture, using connected and geolocated tractors and machines to optimize the energy spent and to improve the daily routine. The increasing growth of population and IoT infrastructure raises concerns about the feasibility of accommodating and managing interconnected objects and people effectively. Therefore, the W3 thinks about a new paradigm for identifying subjects, named the Decentralized Identity (DID) [4].

- Such a system is owned by the participants which means a total elimination of a single point of failure.
- Each entity should claim an attribute relation to the identity (themselves) and get trusted by an authority or an attested and verified one.
- The participants implement a system to agree on a common state.
- No single company controls the sensitive part of the system.
- Decentralizing the identity eliminates the risk of stealing a database storing millions of identifiers.
- The credentials should be stored in the same place as the owner (identity).

People can take back the ownership of their identity. With DID, you can manage the identity by yourself using a private key stored on a wallet; a very common example is social media. We can imagine our network in a special social network moved with our identity to another network, on the other side, so there is no need for companies to build a new social graph from scratch for any new social media. The ability to consent to the type of data you provide to a third party is the key in a DID system. This technique is achieved by Zero Knowledge proof which "are an elegant technique to limit the amount of information transferred from a prover A to a verifier B in a cryptographic protocol" [2]. As defined in the original GMR paper "a buyer A can assert to a seller B that his or her age is more than 18, which allows him or her to buy some specific product, without revealing the birth date" [3].

This paper proposes an implementation of a DID, which will allow an entity to transact in a seamless way with a decentralized ecosystem. A DID can be seen as a global unique identifier. In section 2, we present several DID projects that are relevant to our decentralized system under development. Moving on to section 3, we introduce the syntax specific to our system and provide an overview of the current architecture. Section 4 focuses on the DID Document and its role in addressing the challenge of public key rotation. In section 5, we showcase our architecture and propose the incorporation of a new layer to address the scalability issue.

II. RELATED WORK

DID systems have gained traction as an alternative to centralized identity management, ensuring security and privacy has emerged as a major challenge. Sybil attacks, secure key management, and privacy risks are just some of the issues that need to be addressed. In recent years, several studies have proposed solutions that leverage decentralized authentication mechanisms, consensus protocols, layered key

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management approaches, and privacy-enhancing technologies.

The article "Self-Sovereign Identity Systems Evaluation Framework" [5] proposes a framework to evaluate self-sovereign identity (SSI) systems based on four dimensions: technical, functional, non-functional, and organizational. The technical dimension assesses the system's architecture, security, privacy, and interoperability. The functional dimension evaluates the system's features and capabilities, such as identity issuance, management, and verification. The non-functional dimension assesses the system's performance, usability, accessibility, and user's experience. Finally, the organizational dimension evaluates the system's governance, legal compliance, and economic sustainability. The proposed framework provides a comprehensive and structured approach to evaluating SSI systems, enabling a systematic comparison of different SSI solutions, and facilitating their adoption and implementation.

The DID solutions are often built on existing blockchains , such as Ethereum, Bitcoin, and others. While this approach provides a high degree of decentralization and security, it can also lead to scalability issues due to the limited processing capacity of these blockchains.

A. uPort

uPort [6] is built on the Ethereum blockchain and is available as open-source software. The primary goal of uPort is to provide DID services for all users. To create an identity, a user can use the dedicated mobile application provided by uPort, which stores all their identity data, including private keys for signing and sharing claims.

Once an identity has been created, two smart contracts named "controller" and "proxy" are automatically deployed onto the Ethereum blockchain. These contracts serve as the backbone for managing and controlling the user's identity and provide a secure and decentralized way of verifying identity and sharing data.

The uPort project has divided into Serto and Veramo, both dedicated to decentralizing the internet and restoring data control to individuals.

B. Sovrin

Sovrin [7] is a DID network built on Hyperledger Indy, which uses a "trust anchor" model and a modified Practical Byzantine Fault Tolerance consensus algorithm to establish the authenticity of verifiable credentials. Sovrin offers an SDK and APIs for easy integration and has a transparent governance model overseen by the Sovrin Foundation.

C. EverID

EverID [8] focuses on meeting the identity and the needs of developing countries for data management .The platform leverages blockchain technology, biometrics, and mobile devices to create a secure and verifiable identity for individuals in underserved communities. With a biometric verification system and mobile wallet feature, EverID aims to provide individuals with access to essential services and participation in the global economy. Built on the Komodo platform, EverID is highly scalable and provides fast and secure transactions through its hybrid consensus mechanism.

III. DID Infrastructure or DID Public Key Infrastructure

We need to introduce some definitions for the coming few sections, so let's gather the various definitions we need into one place:

- DID is a unique identifier; in our implementation it is generated from the public key generated by the DID issuer.
- The DID issuer generates the DID, writes the mapping of DID and DID Doc to Data registry. The DID issuer digitally signs any data and gives credential or VC to the Holder.
- Data Registry is the storage of the mapping of DID, and DID Doc, in our case, is a Blockchain.
- DID Doc is the DID documents which contain information associated with a DID. They typically express verification methods, for instance cryptographic public keys [9].
- DID Resolver resolves the DID-to-DID Doc from the Data Registry.
- A VC is a verifiable credential like a passport which serves to attest specific information about an entity associated with a specific DID. VCs can be created by any entity of the system and issued to the holder of the VC.

During a decentralized transaction, a VC Holder presents their VC to another entity, the verifier which is an entity, or an individual can verify the data of the VC as presented by the holder (Fig. 1).

The verifier can cryptographically check if the VC is connected with the Issuer and the Holder.

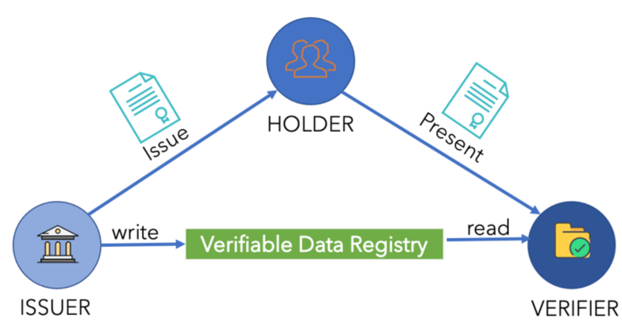

Figure 1. DID Architecture.

In the next section, we will discuss the DID Document and its role in addressing one of the major challenges associated with key rotation.

IV. DID Document and Key Rotation Issue

DID document is a type of metadata that contains information about a specific DID. This includes the public

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keys that are associated with the DID. The DID document is often stored on a decentralized ledger called a Verifiable Data Registry (Fig. 1) or in a distributed file system and it is used to enable secure and decentralized identity management.

In order to maintain the security of a DID, it is often necessary to rotate its public key(s) periodically. This can be necessary in cases of compromise or to comply with best practices. When a public key is rotated, it is important to update the DID document to reflect the new key(s) associated with the DID.

To update the DID document with new public key(s), the DID owner can create and sign a new version of the document with their private key. This new version of the DID document can then be published to the decentralized ledger or distributed file system where the previous version was stored (Figure 2). This process allows the new public key(s) associated with the DID to be made available for use.

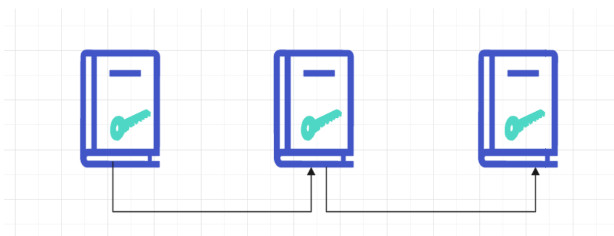

Figure 2. Multiple Version Chained of DID Document.

It is important to note that the process of public key rotation may vary depending on the specific DID system and implementation being used. Nevertheless, maintaining the security of DIDs is critical for ensuring the integrity of decentralized systems and their ability to support secure and DID management.

V. Our Contributions

Using a custom-built blockchain solution and the Substrate framework, our DID architecture addresses scalability challenges, ensuring a robust and high-performing ecosystem.

A. *Implementation Using Substrate Framework*

Our DID architecture utilizes a custom-built blockchain solution to overcome scalability issues present in existing blockchain platforms like Ethereum. We have chosen to employ the highly flexible and modular Substrate framework to enable tailoring of our DID implementation to our specific use case requirements. This approach offers the necessary scalability [10] and performance characteristics to facilitate a robust and reliable DID ecosystem. Substrate "enables developers to quickly and easily build future proof blockchains optimized for any use case" [11].

We will build our DID system on top of this framework because "Substrate takes the hard work out of blockchain development without imposing limits often found in other frameworks, it allows development teams to quickly build blockchains based on academically-researched and field-tested code that have proven their worth on many live networks worth billions of dollars" [12].

In this paper, we will show you how to create a custom pallet which is the key concept of substrate Framework. It will contain the logic code for our blockchain application. These Pallets are built with libraries called Frame, as well as the Rust programming language. Frame includes functions that make it very simple to build our application logic.

We need three components to build our DID system; the first is the DID pallet. The second is the VCS pallet, and the last one is the attestation pallet. The DID pallet is responsible for the DID creation and its storage on the blockchain.

The DID pallet is a critical component of our decentralized systems. It enables the creation, management, and control of Decentralized Identifiers (DIDs). Specifically, the DID pallet provides three core operations: create, update, and revoke, that allow DID owners to manage their identities within the blockchain system. By leveraging blockchain technology, DIDs are stored in a decentralized and tamper-proof manner, ensuring their immutability and high level of security.

In addition to the DID itself, the DID pallet also stores metadata related to the identifier. While some of this metadata is stored directly on the blockchain, other types of metadata will be stored on external databases to optimize storage requirements. For example, entity-related information, like the name and the logo of the DID owner may be stored on external databases.

This hybrid approach to DID management enables users to leverage the benefits of both blockchain and external databases to store and manage their identity-related metadata. It also provides a scalable solution regarding the performance issue.

The DID pallet at this level contains DID creation function called DID_create (1) and one struct named Details which store the details about DID on the blockchain.

(1) pub fn did_create(origin: OriginFor<T>, signing_key: T::SigningKey, boxing_key: T::BoxingKey, did_doc_ref: Option<Vec<u8>>) -> DispatchResult {}

The VCS pallet is responsible for the creation of Verifiable Credentials and revoke. The VCS is hashed and stored on the blockchain with the vcs_create function (2).

(2) pub fn vcs_create(origin: OriginFor<T>, hash:T::Hash) -> DispatchResult {}

Finally, the attestation pallet, which is responsible for the VCS trust (3), in this step is a trusted entity. For example, like a university will trust any data like a certification or a license, or any type of data regarding the DID and a certain claim.

(3) pub fn attestation_create(origin: OriginFor<T>, claim_vcs:T::Hash,vcs_hash:T::Hash) -> DispatchResult {}

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B. Distributed Real Time Layer

Our DID architecture includes a distributed microservices layer (Figure 3) to manage DID metadata, for example VCS metadata, DID metadata, and Issuer metadata. This layer enables instant DID document resolution without requiring blockchain requests. Any changes to the Public Key Infrastructure are immediately reported to this layer via an Event System, ensuring that all metadata remains up-to-date and accurate.

Every subject {ISSUER,HOLDER,VERIFIER} in our scenario will receive a DID (decentralized identifier) that conforms to a particular format according to the W3C standard [4].

As an illustration, consider Alice's decentralized identifier, which can be constructed using her public key in the following manner:

did:dido: {Subkey(5GrwvaEF5zXb26Fz9rcQpDWS57CtERHpNehXCPcNoHGKutQY)}

Here, the "Subkey" function generates a public key derived from the Root public key.

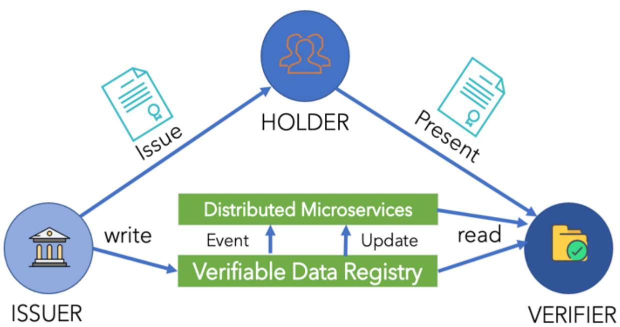

Figure 3. New Architecture Adding a Real Time Layer.

In our system architecture, a trusted entity, such as a university will possess a VC that they can use to sign and distribute to a particular HOLDER. This cryptographic proof will be recorded on our blockchain as an attestation.

The HOLDER will provide evidence to a VERIFIER, for example by displaying a QR code.

The VERIFIER will verify the evidence provided by querying our decentralized microservices layer.

VI. Conclusion

The issuer, holder, and verifier are key components of a DID system. Our work aims to create a DID system that enables secure and privacy-preserving interactions between issuers, holders, and verifiers by connecting the pallets responsible for managing the different components of the system, as shown in Figure 3. By establishing clear and well-defined links between the pallets, the system can work together efficiently and securely. The linking of pallets is crucial for ensuring the reliable exchange of identity information and creating a robust and privacy-preserving SSI ecosystem that can be trusted by all parties involved.

We are incorporating an additional microservices layer to manage the scalability issues that arises from using blockchain technology. Our blockchain serves as a secure ledger, while the microservices layer serves as a cache.

At this stage, we conduct tests using multiple approaches, extending the runtime level, client level, and off-chain level. We also attempt to request changes in the blockchain core when they arise.

This approach will enable us to develop a truly decentralized identity system that can handle a large volume of requests.

References

[1] ISO/IEC JTC 1. (2014). Internet of things: A review of frameworks, standards and action plans.

[2] Oscar Avellaneda, et al. "Decentralized Identity: Where Did It Come From and Where Is It Going?". [Online]. Available from: https://doi.org/10.1109/MCOMSTD.2019.9031542 December, 2019

[3] U. Feige, A. Fiat, and A Shamir "Zero-Knowledge Proofs of Identity", in Journal of Cryptology. [Online]. Available from: https://link.springer.com/content/pdf/10.1007/BF02351717.pdf

[4] M. Sporny, D. Longley, M. Sabadello, D. Reed, O. Steele, C. Allen "Decentralized Identifiers (DIDs) v1.0 Core architecture, data model, and representations".[Online]. Available from : https://www.w3.org/TR/did-core/

[5] A. Satybaldy and M. Nowostawski "Self-Sovereign Identity Systems: Evaluation Framework".[Online]. Available from: https://www.researchgate.net/publication/339836401_Self-Sovereign_Identity_Systems_Evaluation_Framework March 2020

[6] O. Dib and K. Toumi, "Decentralized Identity Systems: Architecture, Challenges, Solutions and Future Directions".".[Online]. Available from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3785452 March 2021

[7] L. Stockburger, G. Kokosioulis, A Mukkamala, R. R. Mukkamala, and M Avital, "Blockchain-enabled decentralized identity management: The case of self-sovereign identity in public transportation".".[Online]. Available from: https://www.sciencedirect.com/science/article/pii/S2096720921000099 June 2021

[8] B. Reid and B. Witteman, "EverID WHITEPAPER" https://neironix.io/documents/whitepaper/6176/EverID_White paper_v1.0.2_July2018.pdf. ".[Online]. Available from : https://neironix.io/documents/whitepaper/6176/EverID_Whitepaper_v1.0.2_July2018.pdf July 2018

[9] W3C Recommendation, Decentralized Identifiers (DIDs) v1.0 Core architecture, data model, and representations W3C Recommendation, https://www.w3.org/TR/did-core/#dfn-did-documents

[10] A. I. Sanka and R. C. C. Cheung, "A systematic review of blockchain scalability: Issues, solutions, analysis and future research".[Online]. Available from: https://www.sciencedirect.com/science/article/abs/pii/S1084804521002307 December 2021

[11] Gavin Wood, et al. "Substrate Framework" https://docs.substrate.io/ June 2023

[12] A. El akroudi, " Data Trust Protocol" https://github.com/lsroudi/DataTrustProtocol/ June 2023

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BeeKnote: Voice Chatbot Assistant for the Beekeepers

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***Abstract*—With the continuous advancement of Artificial Intelligence technologies, chatbots assistants become very popular lately due to their unique characteristics in improving human-computer communication thanks to the Natural Language techniques to process and understand natural human language, and this makes the chatbots assistants show a positive impact in enhancing the user experience for the customers and increasing the business profit for the stakeholders in almost every field, including the beekeeping. In fact, due to the different encountered challenges by the beekeepers on their work, the need for chatbots to assist them was clearly expressed in many surveys. In this paper, firstly, a state of the art is presented about existing solutions as chatbot assistants in the agriculture and beekeeping field before presenting "BeeKnote". Our chatbot assistant aims to assist the beekeepers in their work by extracting relevant information from the vocal commands. The "BeeKnote" specificity is in their flexible architecture that addresses the limitations of the related work and provides a new approach to assist the beekeepers by offering them a hands-free experience.**

***Keywords*—Vocal assistance; Natural language processing; Natural language understanding; Beekeeping; Smart agriculture.**

I. INTRODUCTION

Beekeeping is the art of cultivating bees in order to obtain from this industry the maximum yield with the minimum expense by providing the hive with a perfect environment that will ensure the maximum productivity of the bees that are inside [1]. Besides being a profitable business, beekeeping is considered a crucial field that is essential to the balance of ecosystems and the assurance of food security. Indeed, bees are the key actors of biodiversity, as around 85% of flowers are pollinated by them, and the success of the different agriculture branches is dependent on the success of the pollination process by the honey bees in different countries [2].

However, nature takes its course, and our influence disrupts normal natural processes, altering the balance of natural perfection, which has led to the decline of honey production all over the world and make the production of high-quality honey a more complex goal to be achieved. For example, in France, despite being considered one of the big producers of honey, the volumes of imported honey thus increased by 36% between 2010 and 2020 (6% in 2020) [3].

Consequently, providing an assistant to guide the beekeepers on their work and increase their productivity is important, and chatbots can be an appropriate way to help the beekeepers due to their nature of being user-friendly and convenient in the beekeeping environment by facilitating any average user to interact with any device, anywhere and at any time, without the need of special skills or training by involving a variety of written or oral natural communication forms in order to simulate conversations.

In fact and according to a survey carried out by "ITSAP" in 415 beekeepers [4], voice inputs(77%) and data storage(72%) are already wanted features for the beekeepers.

Additionally, "the Preservation of Bee colonies" and "minimizing the beehives inspections" are among the top 3 most important areas for beekeepers, and it's confirmed that a "Digital notes" app is considered a valid solution to fulfill these needs [2].

However, the usage of innovative technologies that may help the stakeholders and the workers in the agriculture field (including the beekeepers) is still limited [5]. "ITSAP" survey shows that "practicality in the field" (around 15%), "the complexity of the developed solutions" (around 15%), and "the data loss or corruption" (around 10%) are considered the major factors that prevent the beekeepers from cooperating with the existed platforms in the beekeeping field [4].

This paper is organized as follows, Section 2 introduces a comparative survey of the existing chatbots assistant in the agriculture and beekeeping field, the Section 3 will focus on presenting "BeeKnote" our newly developed chatbot assistant for beekeepers that aims mainly to cover the limitation of the mentioned systems by providing a user-friendly, accurate and natural language-based assistant for the beekeeping business, Section 4 presents a discussion about the obtained results from testing the system components and Section 5 provides the summary of the work and future plans to improve the beekeeper's experience while using our system.

II. RELATED WORK

Chatbot assistant systems are not a new area of research, they are widely used in different fields, such as e-commerce, educational support, and customer service [6]. However, according to our research, there are few and limited efforts to build chatbot assistants in the field of agriculture in general and in the field of beekeeping in particular. This paper will focus on mentioning the founded chatbot assistants applied in

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the field of agriculture in general, or exclusively in the field of beekeeping, presenting their offered functionalities and the implementation technologies used.

- Iot-AgriBot [5]: they developed a "Facebook Messenger" chatbot that took any natural language textual/vocal input entered by the user and passed it to “DigitalFlow”: the Google AI platform, which will establish a connection with the concerned IoT agricultural device, in order to provide monitoring information (such as the temperature, and taking the control of the equipment)
- Chatbee [6]: this system consists of answering pre-defined questions related to beekeeping production, it is developed using the closed source code Google AI platform: “Degitalflow“ in the form of a "Telegram" bot.
- API digital bot [7]: this work aims to develop a system to remotely monitor the connected hives with embedded IOT systems, providing real-time information to the bee-keeper. The system was implemented in the form of a "Telegram" bot and the communication with the system is done through predefined commands (for example, the command "/start" is used to perform the authentication and initialize the communication with the chatbot, and "/ultima" is used to get the latest records from the connected beehives).
- LINE [8]: LINE is an interactive chatbot in the form of an Android mobile application where the user can ask about the state of a specific plant (temperature, humidity, soil moisture, etc.) by using IOT devices as a sensors that transmit data related to air humidity, soil moisture, light conditions, and ambient temperature of the connected plant. Communication with this mobile app is possible with natural human language thanks to using Natural Language Processing (NLP) techniques to perform the Natural Language Understanding (NLU) of the provided question by the farmer.
- Zhang et al. [9] designed a FAQ chatbot in the agriculture field, the predefined template-based questions will be answered using AIML (Artificial Intelligence Markup Language) technique while the service-based questions will be answered using Latent Semantic Analysis (LSA) technique, these two techniques are considered as prede-cessors to the modern NLP techniques.
- Symeonaki et al. [10] proposed an agent chatbot system that is capable to monitor and control a group of IOT devices composed of boiler, fan, and lighting controllers installed in the greenhouse in order to control the environ-ment inside the greenhouses using a mobile application with natural human language thanks to the integration of NLP and NLU techniques, the system offers also the control of a plant water demand and consumption
- Beeking [11] (cited in [2]): it is a mobile app and portal that was developed by the SIA BeeTech Services, this app is used by more than 400 beekeepers in Latvia and almost 500 beekeepers abroad. Among the several features offered by this portal, there is the vocal recording option. Regrettably, there isn’t an integrated intelligent assistant that can understand what the beekeeper has said.
- AGRI-QAS [12]: this Question-Answering system is developed to be a domain-specific question-answering system targeting the agriculture domain. Its purpose is to help farmers get information and resolve their queries related to agriculture in the form of FACTOID questions, such as ’which’, ’what’, ’who’, and where. It uses a Question Classifier (diseases, pests, weeds, crops, etc.) to detect the question subject and domain-specific named entity recognizer to find out the best answer. For example, for a question seeking the name of a crop, a Named Entity Recognizer (NER) is used to find candidate crop names from the ranked documents.
- ADANS [13]: this system presents a semantic question-answer system on agriculture developed using a combi-nation of NLP and semantic web technologies, in contrast to the previously cited systems that used database-based data to do the learning process, this system is fed by an ontology-based data, which has a more complicated structure than relational databases, which is a time-consuming task.

Table I summarizes the different main characteristics of each mentioned system and positions our system “BeeKnote” among them.

Unfortunately, and as it can be concluded from Table I, according to our research, we have not found any paper that presents or mentions the existence of an AI-based vocal chat-bot assistant in the field of beekeeping field that integrates the NLP/NLU technologies to understand the beekeeper’s vocal and taking in consideration the specific working conditions (wearing the beekeeper’s suit, the possibility of not being able to hold the phone and use the hands while manipulating the app, etc.) by offering them a hands-free experience thanks to real-time hot-word detection.

In order to address these limitations, we propose the fol-lowing system design and implementation.

III. Proposed Approach

“BeeKnote” aims to address the limitations of the other agent-based chatbot systems in the beekeeping domain. The system can be accessed by installing the “BeeKnote” Android App on a mobile device with internet access provided in order to do the cloud database storage and communication with the different developed and deployed APIs and AI models.

A. BeeKnote main functionalities

After being authenticated, “BeeKnote” offers mainly three principal features:

1) **Recording and Understanding the beekeepers’ vocal commands:** all the commands to be treated aim to store information related to the beehive being inspected at that time (which beehive?, which time? which value? which metric?), these commands fall into four areas: weight-related commands, humidity-related commands, internal temperature-related commands, and external

TABLE I. COMPARAISON TABLE

	Iot-AgriBot [5]	Chatbee [6]	API digital bot [7]	LINE [8]	Zhang et al. [9]	Symeonaki et al. [10]	Beeking [11]	AGRI-QAS [12]	ADANS [13]	**BeeKnote**
[2ex] Human language communication	✓	✓		✓	✓	✓	✓	✓	✓	✓
Mobile devices support	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Database writing	✓					✓	✓			✓
Beekeeping-specific chatbot		✓	✓				✓			✓
NLP/NLU-based learning	✓	✓		✓	✓	✓		✓	✓	✓
Independent from IOT devices		✓			✓	✓	✓	✓	✓	✓
Independent from other messaging applications				✓		✓	✓	✓	✓	✓
Interaction with the user	✓	✓	✓	✓	✓	✓		✓	✓	✓
Vocal inputs support	✓						✓			✓
Vocal inputs understanding	✓									✓
Vocal hot-word detection										✓

temperature-related command, after achieving the NLU of the command, it will be stored locally on-device waiting for the manual validation/rejection by the beekeeper, the NLU part will be well detailed below.

2) **Cloud Storage of the vocal intent after the validation:** once the command is validated by the user, the application will send an HTTP request to an API, which will store the command content (beehive name, value, metrics, etc.) in the cloud in order to assure the data preservation.
3) **Rejection of the command:** we see that offering the user a manual rejection of the command is important for the precaution and handling of the edge cases (misunderstanding of the command, saying false information, inappropriate record, etc.).

Additionally, and for the sake of improving the beekeeper's experience while using our Android app and taking into consideration their particular condition while working, a hand-free experience is provided where the user can communicate with the app by the pronunciation of predefined keywords.

B. BeeKnote global system architecture:

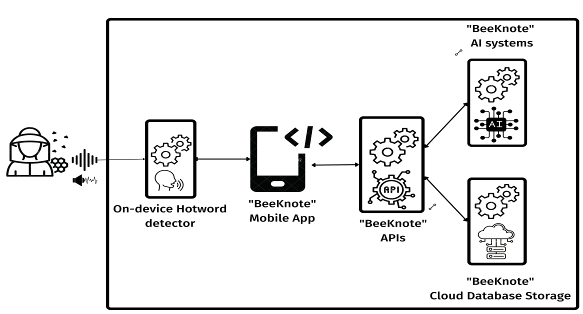

Figure 1. BeeKnote global system architecture

As shown in Figure 1 and in order to fulfill our three major features, the system is going to need a Mobile App with an integrated hot-word detector to assure the hand-free experience by toggling the recording, the validation, and the rejection by saying predefined keywords. Additionally, the mobile app will be connected to the developed APIs, which are going to be the portal to communicate with our AI systems to achieve the NLU and the cloud database storage to store the commands and their interpretations on the cloud in a foolproof manner.

C. BeeKnote System Components

We propose a complex system composed of:

1) Automatic Speech Recognition (ASR) System: "Speech Recognition" is the process of converting a speech signal to a sequence of words by means algorithm implemented as a computer program [14]. ASR is an important technology to enable and improve human-computer interactions [15].

The accuracy of speech recognition models is measured by the "Word Error Rate" (WER), which is defined as: "The number of errors divided by the total words". Fadel et al. [16] presented a table summarizing the evaluation of French speech recognizer systems by the WER metric. All the cited systems give a WER bigger than 9% (from 9.6% to 47.41%).

In "BeeKnote", "Whisper" [17] is used, it is an open-source multilingual and multitask deep learning speech recognition system provided by the "Open AI" community launched officially in September 2022.

"Whisper" gives a WER equal to 8.3% in the "Fleurs" database for the French language [18], which proves his performance compared to the alternative ones.

2) Hot-word detection system: Hot-word detection is the application's constant waiting mechanism for a specific word(s) [19], when the predefined word is heard, the application recognizes it and activates a certain predefined process [20]

For "BeeKnote", predefined words are needed to launch/stop the audio recording, the validation of the command, and the command rejections to assure a hands-free experience for the beekeepers, and for that, "Porcupine" is used [21].

"Porcupine" is a lightweight and production-ready hot-word detector that shows the biggest accuracy (91%) in "work word benchmark" compared to two famous hot-word detectors: "Snowboy" (68%) and "PocketSphinx" (52%) [21].

3) Text classification system: Text classification is the task of classifying a document under a predefined category. If d_i is a document of the entire set of documents D and $\{c_1, c_2, \ldots, c_n\}$ is the set of all the categories, then the role of the text classifier is to assign one category c_i for each document d_i [22].

We built a custom multi-classification NLP model that takes as input a text and classifies it according to its intent among four classes: "Weight", "Humidity", "Internal temperature", and "External temperature". For the training, an Excel sheet containing 75 commands and their corresponding classes filled manually by beekeepers is used.

After doing a pipeline of text preprocessing consisting of tokenization, sequence padding, and finally the Stanford Glove embedding, we passed the data into the model to do the training process, and in order to treat the whole sentence, which is composed of a set of words at once and in a single iteration, the model to train must be a sort of a Recurrent Neural Network (RNN) that evaluates the current input as well as what it has learned from past inputs thanks to its internal memory [24].

And for that, deep multi-classification bidirectional Global Recurrent Unit (GRU) [23] neural architecture was built and trained to do the training and the prediction of the commands topic.

The reason behind using GRU instead of a typical RNN or the more-sophisticated one: Long Short term memory (LSTM), is that the GRUs train faster and seem to perform better for small amounts of data, but LSTMs have greater computational complexity [24].

4) Named Entity Recognizer (NER) system: NER is the problem of locating and categorizing important nouns and proper nouns in a text. For example, names of persons, organizations, and locations are typically important. NER plays an important role in information extraction [25]. For "BeeKnote", a NER system is crucial to do the information extraction from the beekeeper command, such as beehives names, values, and metrics to store or even the qualitative description, such as "heavy", "hot", "too much vapor", etc. There are several pre-trained models, most are for the English language and they are trained for general-use entities (like the locations and the organizations). In our case, we defined 11 domain-specific entities that we need to extract from the beekeeper commands, Figure 2 shows the weight-related predefined entities as an example.

There were some efforts to design from scratch a deep RNN model that would train well in our NER data but unfortunately, it doesn't show promising results, and for this reason, we used CamemBERT to train our custom NER model for the beekeeping domain in the French Language.

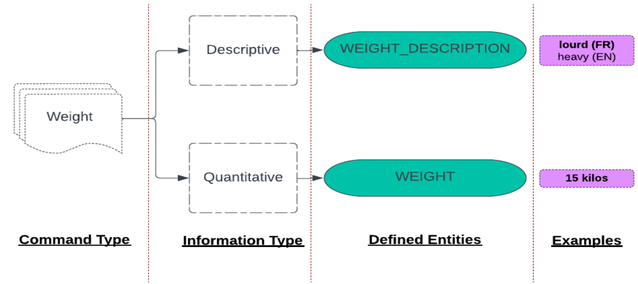

Figure 2. Predefined entities for the weight information

"CamemBERT" is based on RoBERTa, which itself is based on BERT. BERT is a multi-layer bidirectional Transformer encoder, it comes in two sizes: the "BERT-Base" and the "BERT-Large". The "BERT-Base" architecture is 3 times smaller, so it's faster and easier to use while BERT-Large achieves generally better accuracy. "CamemBERT" is used because it achieves higher F1 scores than the traditional NER architectures [26].

To train our NER, "SpaCy" [27] is used as a software library platform where "CamemBERT" was manipulated as a custom spaCy pipeline to train it in our data.

5) First REST API (Flask): this API plays the gateway role by providing an HTTP portal to communicate with the three previous AI systems (ASR, classification, and NER), "Flask" is used as a technology to implement this API since the AI models can be easily plugged, extended and deployed as a web application there and it's a lightweight server [28].

6) Cloud database storage: Cloud storage is crucial in our system to assure data preservation for the beekeepers, "MongoDB" is used as a technology to achieve data preservation due to its simplicity and its flexibility with the data structures, which will assure an easy future extension to our data schemas [29].

7) Second REST API (NodeJS): this API is the portal to communicate with the system cloud database by providing an HTTP interface for that, "NodeJs" is used as a technology since it's well-known for being fast and it allows us to explore a dynamic range of data in real-time easily [30].

8) The Android Application (BeeKnote): our developed Android application will allow the beekeepers to exploit easily our three major functionalities previously mentioned by offering them an easy-to-use interface to communicate with our intelligent chatbot.

D. BeeKnote Workflow System Architecture

Figures 3 and 4 explain the interconnection between the different system components in order to achieve the recording, the understanding, and the validation of the beekeeper's vocal commands.

1) Once our Hotword device detector hears the keyword "Bee note", the mobile app starts the audio recording.

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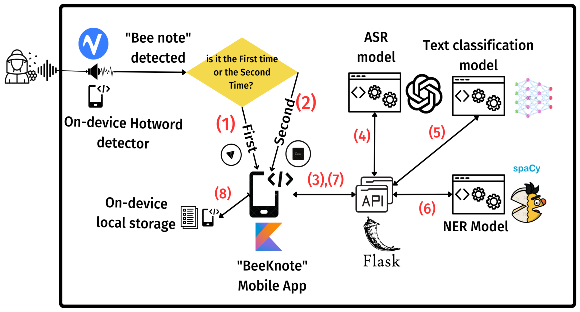

Figure 3. Audio Recording and Understanding Workflow

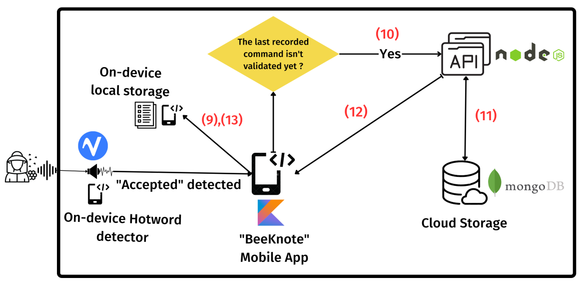

Figure 4. Command validation workflow

2) The record continues until the beekeeper says the same keyword again.
3) The audio will be recorded locally on the device in an MP3 file and it will be sent to the Flask API.
4) The API Transmits the .mp3 file to the ASR system, which will send back the generated textual transcription as a response.
5) The API transmits the generated transcription to our text classifier system, which will send back as a response the predicted class of the said command.
6) Then, the API transfers the transcription to our NER system, which will send back as a response an array of the detected entities and their types.
7) The Android app will receive a response from the API call in 3) the generated transcription, the predicted class, and the detected entities.
8) After confirming the harmoniousness between the predicted class and the detected entities, we store the transcription, the predicted class, and the detected entities in the local storage, waiting for the beekeeping validation.
9) Once the validation keyword has been said "Oui Bee Note", the Android App searches inside its local storage for the latest recorded command.
10) If it's not validated yet, it will be transmitted to the NodeJS API.
11) The NodeJS API sends the appropriate query to MongoDB to store the command interpretation on the cloud.
12) The Android App receives a response from the request sent in 10) a confirmation of the cloud storage with success.
13) The last recorded command status will be changed from "pending" to "validated".

IV. Results and Discussion

In order to measure the accuracy of our developed system, we have built a test dataset composed of 26 vocals (8 for weight, 10 for temperature, and 8 for humidity) where we covered every desired pattern that our system is supposed to understand accurately. This dataset contains 56 entities to detect (15 weight-related, 25 temperature-related, and 16 humidity-related).

A. *Unit Testing*

We have done a unit accuracy test of each component independently before doing an integration test where we measure the accuracy of the whole system by connecting the whole system's components.

1) ASR System results: as it's shown in Table II, three versions of Whisper were used in our test database, while the three have varying percentages of accuracy, they have a convergent execution time, and that's why we picked the 'Large' version for "BeeKnote", which has 76.92% of accuracy

TABLE II. ASR results

Version	Perfect Transcriptions	Avg. Exec (s)
Base	42.3%	**0.328**
Medium	61.53%	1.03
Large	**76.92%**	1.49

2) NER System results: Two versions of CamemBERT were used to train our own NER System and two metrics to measure the accuracy of these two versions were defined and used:

- Detection rate: it measures the ratio of the detected entities inside the commands transcription.
- Accuracy rate: it measures the ratio of the detected AND well-classified entities inside the commands transcription.

In this unit test, we suppose that the ASR system transmits the perfect transcription to our NER.

TABLE III. NER camemBERT-base VS camemBERT-large results

Type	Detection		Accuracy		Avg Exec (s)	
	Base	Large	Base	Large	Base	Large
Weight	100%	100%	**100%**	93%	**0.12**	0.32
Temperature	92%	**96%**	88%	**96%**	**0.10**	0.27
Humidity	**100%**	93%	81%	**87%**	**0.10**	0.27
Total	96%	96%	89%	**92%**	**0.10**	0.33

Table III shows that although camemBERT-large is thrice slower, it has shown just a little improvement in the accuracy rate (3% more accurate).

3) Text Classification system results: Table IV shows that our best classifier has an accuracy of around 70-75% for the three classes.

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TABLE IV. TEXT CLASSIFICATION SYSTEM:

Type	Classified correctly
Weight	75%
Temperature	70%
Humidity	75%
Total	73.07%

B. Integration Testing

Since we noticed that our NER system performs so well that it doesn't need the classification system to assure its consistency, in addition to that, we want to improve the beekeeper experience by allowing him to say a mixture of entities that don't have to be on the same class (for example, allow the beekeeper to store information about the weight and the temperature of a certain hive in the same command), so the transcription generated by the ASR system will be passed only to the NER system in order to get at the end the different entities to store in the cloud.

In this test, we will pass the transcription generated by 'Whipser-large' to our NER systems "camemBERT-large" and "camemBERT-base".

The results in Table V shows that the integration of Whipser-large with our pre-trained camemBERT-large or camemBERT-base gives the same global accuracy (80.35%) with a slight increase in the detection rate for the camemBERT-large (+3.5%) even though it was shown that the camemBERT-large has better accuracy, this can be explained by the camemBERT-large's fault intolerance with the inaccurate transcriptions.

TABLE V. WHISPER-LARGE INTEGRATION WITH CAMEMBERT-BASE VS WHISPER-LARGE INTEGRATION WITH CAMEMBERT-LARGE RESULTS

Type	Detection		Accuraccy		Avg Exec (s)	
	Base	Large	Base	Large	Base	Large
Weight	86%	80%	80%	80%	**+0.13**	+0.32
Temperature	92%	**92%** [1]	80%	**84%**	**+0.11**	+0.38
Humidity	**93%**	87%	**81%**	75%	**+0.10**	+0.52
Total	**91%**	87%	80%	80%	**+0.11**	+0.40

[1] There was a false positive detected entities here: 92% are true positive ones while there was additional 16% detected considered as false positive.

We conclude finally that the integration of "camemBERT-base" with "Whipser-large" is the best to avoid the false positive detected entities and to improve the overall system performance by reducing the response latency to assure a more fluid experience for the beekeepers.

V. CONCLUSION AND FUTURE WORK

This paper presents "BeeKnote", a voice chatbot assistant for beekeepers. This system is able to record and understand the beekeeper's vocal inputs to extract relevant mentioned information related to the beehive state. The system is in a microservices shape, which makes every component easily replaceable by an alternative one, this also assures the system flexibility and the ability to reuse it across different areas of business. The future version of "BeeKnote" may address the limitations of the current version by including an offline version where all the AI models are deployed on the device and the cloud storage of the content of the commands will be done once the mobile is connected to the internet, this would increase the system availability by assuring the chatbot-beekeeper interactions in areas with poor internet coverage. Additionally, and due to the lack of training data, the "Bee-Knote" current version handles semi-structured instructions, where the beekeeper's commands should have a similar format to the commands used in the learning dataset, otherwise, the beekeeper may face inaccurate processing of its command, so assuring that aspect of flexibility can be interesting also.

REFERENCES

[1] Warre, E. (2006) ["L'apiculture pour tous: L'apiculture facile et reproductive"] (Beekeeping for all: Easy and reproductive beekeeping). Revest-Saint-Martin: Coyote ed.Accessed: May 30, 2023. [Online]. Available: http://www.apiculture-warre.fr/.

[2] A. Zacepins, A. Kviesis, V. Komasilovs, V. Brusbardis, and J. Kronbergs, "Status of the Precision Beekeeping Development in Latvia," Rural Sustainability Research, vol. 45, no. 340, pp. 86–92, Aug. 2021, doi: 10.2478/plua-2021-0010.

[3] J.-C. Huet, L. Bougueroua, Y. Kriouile, K. Wegrzyn-Wolska, and C. Ancourt, "Digital Transformation of Beekeeping through the Use of a Decision Making Architecture," Applied Sciences, vol. 12, no. 21, p. 11179, Nov. 2022, doi: 10.3390/app122111179.

[4] ["Enquête «Les apiculteurs et le numérique» | Article | ITSAP."] (Survey "Beekeepers and digital technology" | Article | ITSAP.) https://itsap.asso.fr/articles/enquete-les-apiculteurs-et-le-numerique (accessed May 30, 2023).

[5] E. Symeonaki, K. Arvanitis, P. Papageorgas, and D. Piromalis, "AI-Based Chatbot System Integration to a Social Media Platform for Controlling IoT Devices in Smart Agriculture Facilities," 2021, pp. 193–209. doi: 10.1007/978-3-030-84156-0_10.

[6] A. A. de Oliveira Filho, "Chatbot as Rural Extensionist for Small Beekeepers," in Anais do XIV Encontro Unificado de Computação do Piauí (ENUCOMPI 2021), Sociedade Brasileira de Computação, Nov. 2021, pp. 200–206. doi: 10.5753/enucompi.2021.17772.

[7] D. Ferreira Mojaravscki, ["Apicultura Digital, a Transformação Tecnológica Da Apicultura,"](Digital Apiculture, the Technological Transformation of Apiculture,) in Agrárias: Pesquisa e Inovação nas Ciências que Alimentam o Mundo Vol.I, Editora Artemis, 2020, pp. 23–32. doi: 10.37572/EdArt_0643006203.

[8] R. Gunawan, I. Taufik, E. Mulyana, O. T. Kurahman, M. A. Ramdhani, and Mahmud, "Chatbot Application on Internet Of Things (IoT) to Support Smart Urban Agriculture," in 2019 IEEE 5th International Conference on Wireless and Telematics (ICWT), IEEE, Jul. 2019, pp. 1–6. doi: 10.1109/ICWT47785.2019.8978223.

[9] D. Zhang, X. Chen, Y. Zhang, and S. Qin, "Template-based Chatbot for Agriculture Related FAQs," Jul. 2021, Accessed: May 30, 2023. [Online]. Available: https://arxiv.org/abs/2107.12595v2

[10] E. Symeonaki, K. Arvanitis, D. Piromalis, and M. Papoutsidakis, "Conversational User Interface Integration in Controlling IoT Devices Applied to Smart Agriculture: Analysis of a Chatbot System Design," 2020, pp. 1071–1088. doi: 10.1007/978-3-030-29516-5_80.

[11] "BeeKing - your digital beekeeper app." https://beeking.eu/en/index.html (accessed May 30, 2023).

[12] S. Gaikwad, R. Asodekar, S. Gadia, and V. Z. Attar, "AGRI-QAS question-answering system for agriculture domain," in 2015 International Conference on Advances in Computing, Communications and Informatics (ICACCI), IEEE, Aug. 2015, pp. 1474–1478. doi: 10.1109/ICACCI.2015.7275820.

[13] M. Devi and M. Dua, "ADANS: An agriculture domain question answering system using ontologies," in 2017 International Conference on Computing, Communication and Automation (ICCCA), IEEE, May 2017, pp. 122–127. doi: 10.1109/CCAA.2017.8229784.

[14] S. K. Gaikwad, B. W. Gawali, and P. Yannawar, "A Review on Speech Recognition Technique," Int J Comput Appl, vol. 10, no. 3, pp. 16–24, Nov. 2010, doi: 10.5120/1462-1976.
[15] D. Yu and L. Deng, "Automatic Speech Recognition," 2015, doi: 10.1007/978-1-4471-5779-3.
[16] W. Fadel, I. Araf, T. Bouchentouf, P.-A. Buvet, F. Bourzeix, and O. Bourja, "Which French speech recognition system for assistant robots?," in 2022 2nd International Conference on Innovative Research in Applied Science, Engineering and Technology (IRASET), IEEE, Mar. 2022, pp. 1–5. doi: 10.1109/IRASET52964.2022.9737976.
[17] "Introducing Whisper." https://openai.com/research/whisper (accessed May 30, 2023).
[18] A. Radford, J. W. Kim, T. Xu, G. Brockman, C. McLeavey, and I. Sutskever, "Robust Speech Recognition via Large-Scale Weak Supervision," Dec. 2022, Accessed: May 30, 2023. [Online]. Available: https://arxiv.org/abs/2212.04356v1
[19] M. Skorikov, K. N. J. Omar, and R. Khan, "Voice-Controlled Intelligent Personal Assistant," 2022, pp. 57–65. doi: 10.1007/978-3-030-92905-3_6.
[20] K.-P. Yang, A. Jee, D. Leblanc, J. Weaver, and Z. Armand, "Experimenting with Hotword Detection: The Pao-Pal," European Journal of Electrical Engineering and Computer Science, vol. 4, no. 5, Sep. 2020, doi: 10.24018/ejece.2020.4.5.246.
[21] "Porcupine Wake Word Detection & Keyword Spotting - Picovoice." https://picovoice.ai/platform/porcupine/ (accessed May 30, 2023).
[22] M. Ikonomakis, S. Kotsiantis, and V. Tampakas, "Text classification using machine learning techniques.," WSEAS Transactions on Computers, vol. 4, no. 8, pp. 966–974, 2005.
[23] K. Cho et al., "Learning Phrase Representations using RNN Encoder–Decoder for Statistical Machine Translation," in Proceedings of the 2014 Conference on Empirical Methods in Natural Language Processing (EMNLP), Stroudsburg, PA, USA: Association for Computational Linguistics, 2014, pp. 1724–1734. doi: 10.3115/v1/D14-1179.
[24] A. Shenfield and M. Howarth, "A Novel Deep Learning Model for the Detection and Identification of Rolling Element-Bearing Faults," Sensors, vol. 20, no. 18, p. 5112, Sep. 2020, doi: 10.3390/s20185112.
[25] B. Mohit, "Named Entity Recognition," in Natural Language Processing of Semitic Languages, Berlin, Heidelberg: Springer Berlin Heidelberg, 2014, pp. 221–245. Accessed: May 11, 2023. [Online]. Available: http://dx.doi.org/10.1007/978-3-642-45358-8_7
[26] L. Martin et al., "CamemBERT: a Tasty French Language Model," in Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics, Stroudsburg, PA, USA: Association for Computational Linguistics, 2020, pp. 7203–7219. doi: 10.18653/v1/2020.acl-main.645.
[27] "spaCy · Industrial-strength Natural Language Processing in Python." https://spacy.io/ (accessed May 30, 2023).
[28] P. Singh, "Machine Learning Deployment as a Web Service," Deploy Machine Learning Models to Production, pp. 67–90, 2021, doi: 10.1007/978-1-4842-6546-8_3.
[29] C. Gyorodi, R. Gyorodi, G. Pecherle, and A. Olah, "A comparative study: MongoDB vs. MySQL," 2015 13th International Conference on Engineering of Modern Electric Systems, EMES 2015, Jul. 2015, doi: 10.1109/EMES.2015.7158433.
[30] S. Tilkov and S. Vinoski, "Node.js: Using JavaScript to build high-performance network programs," IEEE Internet Comput, vol. 14, no. 6, pp. 80–83, Nov. 2010, doi: 10.1109/MIC.2010.145.

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Technologies and Tools in Support of the Customer Experience Management Process: A Literature Review

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***Abstract*—There is a trend in organizations to go beyond Customer Relationship Management (CRM) and consider Customer Experience Management (CEM). While CRM software tools are widespread, CEM software tools are more recent and not as refined. Most existing CEM software tools focus on collecting and analyzing feedback from customers. However, the CEM process encompasses several other activities, such as designing the desired customer experience. This paper reviews the literature to synthesize what technologies and tools can assist managers in each activity of the CEM process.**

Keywords-customer experience management; tools; technologies; literature review.

I. Introduction

Gaining and sustaining a competitive advantage is a daunting challenge in today's fast-changing environment. According to some, customer experience is what organizations will now have to compete in to stand out from their competitors [1]. This would be the case in any industry, whether it be banking [2][3][4], hospitality and tourism [5][6][7], communications [8][9], retail [10][11], and online commerce [12][13]. For instance, supply chain management, which used to focus on product development and order processing, is now also looking at Customer Experience Management (CEM or CXM) as a source of competitive advantage [14].

Customer experience can be defined as the "customer sensorial, physiological, psychological responses such as cognitive as well as affective responses evoked by the customer direct (offline) and indirect (online) interactions with the firm or firm offerings across all the touch points throughout the customer purchase journey" [15]. The emotional and sensorial components of the customer experience, as well as the fact that it encompasses all interactions that a customer has with a brand [16], make it challenging to manage.

Naturally, the customer experience is closely related to Information Technology (IT). To begin with, customers often learn about a brand through online advertising and social media [17]. They interact with organizations through various channels, including on their mobile phones, and interact closely with technology even in brick-and-mortar stores (e.g., self-check-out [18]). The simple fact of including IT can improve customer experience even in unexpected settings, such as in temples [19].

Of course, IT is also useful and needed in managing the customer experience. To that effect, CEM software tools have begun appearing on the market, but they mainly focus on collecting and analyzing feedback from customers. While this is helpful, many other activities are required to manage customer experience, such as designing the desired customer experience.

In contrast, Customer Relationship Management (CRM) software tools are a lot more established and cover all activities encompassing the management of customer relationships. For instance, Buttle and Maklan [20] propose four steps to manage customer relationships, i.e., 1) Identify who your customers are and build a deep understanding of them; 2) Differentiate your customers to identify which customers have most value now and which offer most for the future; 3) Interact with customers to ensure that you understand customer expectations and their relationships with other suppliers or brands; and 4) Customize the offer and communications to ensure that the expectations of customers are met. CRM software tools available on the market commonly cover those four steps.

Therefore, organizations run the risk of focusing only on the activities currently supported by CEM software tools, to the detriment of their customers' experience. Thus, to offset the limits of current available CEM software tools, the objective of this paper is to review the literature to identify technologies and tools which can help managers in each activity of the CEM process.

The rest of this paper is organized as follows. Section II discusses customer experience and the steps required to manage it. Section III describes the methodology used to conduct our literature review. Section IV presents the results. Lastly, Section V concludes the paper and gives implications for future research.

II. Customer Experience Management

CEM first appeared in the literature in the late 1990s, when Pine and Gilmore [21] stated in Harvard Business Review that providing experiences was the next discipline that would enable organizations to remain competitive. They explain that although some confuse the delivery of an experience with that of a service, they are two distinct approaches. According to these authors, while products and services are external to the customer, "experiences are inherently personal, existing only in the mind of an individual who has been engaged on an emotional, physical, intellectual, or even spiritual level" [21].

Indeed, customer experience is described as the "aggregate of feelings, perceptions and attitudes" formed by the customer throughout their journey, at each touchpoint [22]. Since customer experience is such a complex, multi-faceted concept, its management is naturally just as intricate. CEM is defined as "the cultural mindsets toward CEs, strategic directions for designing CEs, and firm capabilities for continually renewing CEs, with the goals of achieving and sustaining long-term customer loyalty" [23]. While there is no agreed-upon CEM process in the literature, several similar processes are suggested, some of which are adapted to a particular industry.

Du Plessi and de Vries [24] conducted a literature review and used inductive thematic analysis to describe the CEM process in four steps and twelve sub-steps. The first step is Customer experience understanding, which includes segmenting customers and defining their needs. The second step is Customer experience design, which consists of mapping the desired customer journeys. The third step is Customer experience measurement. The last step, Customer experience change implementation, consists of identifying the gaps between the current and the desired experience, and taking action to close those gaps.

More recently, Rahiman, ShamiZanjani, Manian and Esfidani [25] proposed four high-level CEM stages, each containing steps. They were identified through a systematic review of the literature on the hotel, tourism, and hospitality industry. The four stages are Customer identification, Customer experience design, Customer experience implementation, and Customer experience monitoring. They are very similar to the steps identified by [24] and cover approximately the same activities.

For the remainder of this paper, we have taken together the stages and steps proposed by [24] and [25] to use as a CEM process. They are presented in Table I. While the steps follow a logical sequence, the process is iterative, since the customers, as well as their experiences, are constantly changing.

III. METHODOLOGY

We conducted a literature review with the objective of identifying technologies and tools that can assist management in each step of the CEM process. The first step was to search the relevant literature. The flow diagram is presented in Fig. 1. We searched the online database ABI/INFORM and limited our scope to peer-reviewed articles. A preliminary search informed us that relevant articles used at least the expression 'customer experience' and most contained the word 'technology' or 'technologies'. We also decided to use the keywords 'software' and 'tool' to be as comprehensive as possible. We consequently used three search strings, presented in Fig. 1. The expression "technolog*" was used to account for both singular and plural forms of the word. To focus on articles more closely related to our research topic, we search everywhere except full text. We thereby identified 572 articles, which came down to 438 once the duplicates were removed.

TABLE I. CEM PROCESS

Step	Activities[a]
Customer identification	- Segmenting customers - Assessing customers' characteristics and understanding their needs, expectations, and values - Identifying past experiences and experiences with other competitors
Customer experience design	- Developing a strategy - Designing/mapping customer journeys and touchpoints - Designing services - Prioritizing touchpoints
Customer experience implementation	- Identifying gaps in experience design versus current organizational capability - Prioritizing improvement initiatives - Developing touchpoints - Interacting with customers - Responding to customers' needs, expectations, and values - Engaging with customers and their communities - Personalizing services
Customer experience monitoring	- Monitoring experiences - Defining internal and external measurements - Implementing escalation mechanisms - Adapting touchpoints

a. Synthesized from Du Plessi and de Vries [24] and Rahiman, ShamiZanjani, Manian and Esfidani [25]

The second step consisted of screening the identified studies. We read the identified articles' title and abstract. Fourteen articles were excluded because they were not in English.

Then, in the third step, we read the articles relevant to our research topic in their entirety. We found 51 articles that proposed technologies and/or tools that can be helpful in the CEM process. It should be noted that the use of the Internet

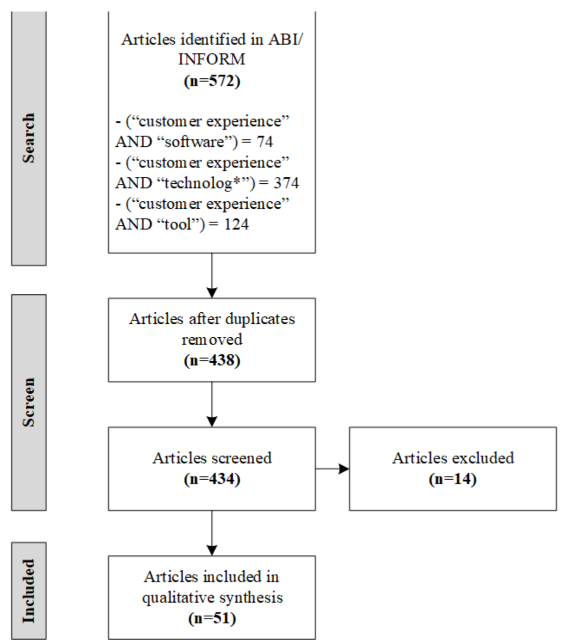

Figure 1. PRISMA flow diagram of the review process.

was not retained, as it is broad and omnipresent in all organizations nowadays. Websites and technologies that are specific to a certain industry, such as exhibition service systems [26], were also excluded. The included articles' publication dates range from 1998 to 2023, with five articles published before 2005 and 33 since 2018.

Once we had extracted all technologies and tools, we performed a qualitative synthesis to collect them all in a unified list. As a final step, we identified which technologies and tools can be used in each step of the CEM process. The results are presented in the next section.

IV. RESULTS

After reviewing the literature as described in Section III, we were able to identify 35 technologies and tools that can assist in managing the customer experience. They are presented in alphabetical order in Table II. A few similar technologies were gathered, such as artificial intelligence and machine learning.

Table III presents in alphabetical order the technologies and tools that can assist management in each step of the CEM process. The steps are those identified in Table I in Section II. The activities composing each step are not repeated to lighten the presentation. Some technologies and tools can be useful in more than one step and thus appear more than once in the table.

It is no surprise that the first step of the CEM process, Customer identification, can be supported by technologies such as analytics, data mining, and database management. These technologies are helpful in segmenting customers, assessing their characteristics, and understanding their needs.

The second step of CEM, Customer experience design, consists primarily of designing the customer journeys and experiences as a whole. Customer experience/journey mapping and modeling tools are thus essential. Co-creation is a prominent concept in customer experience literature. To that end, technologies/applications enabling co-creation allow organizations to engage customers in the design of their customer experience. Although this step is central to CEM, very few technologies and tools were found. However, designing the customer experience is a crucial step of CEM. Indeed, the implementation can only be as good as the design. Therefore, there seems to be an opportunity to explore what technologies and tools could potentially support customer experience design.

The third step, Customer experience implementation, is the one for which the most useful technologies were found. This is mainly because there exist a plethora of different technologies and tools that allow organizations to interact and engage with their customers, such as Artificial Intelligence (AI), Augmented reality (AR), Virtual Reality (VR), call centers, chatbots, digital kiosks, monitors, messaging applications, social media, smart devices, etc. Digital twins, which are "a dynamic virtual representation of a physical object or system across its lifecycle" [27] also allow organizations to interact with customers, as well as to collect data that is useful in the next step of the CEM process, i.e., Customer experience monitoring. Balanced scorecards, on the other hand, are useful for prioritizing improvement initiatives.

TABLE I. TECHNOLOGIES AND TOOLS IN SUPPORT OF THE CEM PROCESS

Technologies/tools	References
Analytics (text analytics, descriptive analytics, predictive analytics, prescriptive analytics)	[28][29][30]
Artificial Intelligence (AI)/Machine learning	[28][31][32][33][34][35][36]
Augmented Reality (AR)	[11][12][36][37][38][39][40]
Balanced Scorecard (BSC)	[41]
Big data, data mining	[29][42]
Call center technology (Voice Response Units (VRU) and Interactive Voice Response (IVR))	[43]
Chatbots	[28][30][33][44][45][46][47]
CRM tools/software	[6][48]
Customer experience/journey mapping and modeling tools	[28][29][49][50][51]
Customer identity card	[43]
Database management	[6]
Digital kiosk	[18][43][52][53]
Digital twins	[27][32]
Drones	[11]
(Face) recognition technologies	[30][36]
Geolocation technology, location-based and wearables	[28] [32][36]
Human resources software	[6]
In-store tablet, touchpoint, monitor, LCD screen, multi-touch display	[30][37][54][55]
Internet of Things (IoT)	[11]
Messaging applications	[28][30]
Near Field Communication (NFC)	[56]
Net promoter score	[28][29][30]
Neuroscience	[32]
On-line catalogues	[57]
Property management system	[6]
Quick Response (QR) code	[37]
Radio Frequency Identification (RFID)	[55][58]
Robotic Process Automation (RPA)	[59]
Self-service technologies	[11][18][33][60][61][62][63]
Smart services/devices	[64][65]
Social media	[6][7][18][30][32][66][67]
Technologies/applications enabling co-creation	[17][68]
Video recording	[69]
Virtual Reality (VR)	[32][36][37][70]
Web services	[71]

There is also a considerable number of relevant technologies for the last step of CEM, which is Customer experience monitoring. Indeed, analytics, data mining, chatbots, geolocation technology, Internet of Things (IoT), and video recording are all examples of technologies and tools that can be used to measure customer experience and flag incidents. CRM tools/software can also be used and they themselves contain powerful analytics capabilities.

V. CONCLUSION

This literature review allowed us to identify 35 technologies and tools that can help management in the CEM process, which were associated with the specific step(s) in which they can be used. This contributes to assisting organizations to manage the customer experience process from start to finish, thereby improving customer experience.

TABLE II. TECHNOLOGIES AND TOOLS RELEVANT TO EACH STEP OF THE CEM PROCESS

Step	Relevant technologies and tools
Customer identification	- Analytics - Big data, data mining - Database management
Customer experience design	- Customer experience/journey mapping and modeling tools - Technologies/applications enabling co-creation
Customer experience implementation	- Artificial Intelligence (AI)/Machine learning - Augmented Reality (AR) - Balanced Scorecard (BSC) - Call center technology (Voice Response Units (VRU) and Interactive Voice Response (IVR)) - Chatbots - Customer identity card - CRM tools/software - Database management - Digital kiosk - Digital twins - Drones - (Face) recognition technologies - Geolocation technology, location-based and wearables - Human resources software - In-store tablet, touchpoint, monitor, LCD screen, multi-touch display - Internet of Things (IoT) - Messaging applications - Near Field Communication (NFC) - On-line catalogues - Property management system - Quick Response (QR) code - Radio Frequency Identification (RFID) - Robotic Process Automation (RPA) - Self-service technologies - Smart services/devices - Social media - Technologies/applications enabling co-creation - Virtual Reality (VR) - Web services
Customer experience monitoring	- Analytics - Big data, data mining - Call center technology (Voice Response Units (VRU) and Interactive Voice Response (IVR)) - Chatbots - CRM tools/software - Database management - Digital twins - (Face) recognition technologies - Geolocation technology, location-based and wearables - In-store tablet, touchpoint, monitor, LCD screen, multi-touch display - Internet of Things (IoT) - Messaging applications - Neuroscience - Social media - Radio Frequency Identification (RFID) - Smart services/devices - Video recording

This study has some limitations. The scope of our research was limited, as we only searched in one database. Moreover, we did not find any technology covering all four steps of the CEM process in our review of the literature. This could cause a lag between the time a weakness in the customer experience is flagged during customer experience monitoring and the time it is addressed during the continuous improvement of the customer experience design. There is thus a need for a system capable of covering all activities of CEM. This could allow organizations to be more agile and make their customer experience evolve seamlessly, thereby giving them a non-negligible competitive advantage. As a future research avenue, we suggest investigating how such a system could be designed, or how some of the existing technologies and tools could be connected and organized to work seamlessly as one system.

REFERENCES

[1] T. Keiningham, J. Ball, S. Benoit, H. L. Bruce, A. Buoye, J. Dzenkovska *et al.*, "The interplay of customer experience and commitment," Journal of Services marketing, vol. 31, no. 2, pp. 148-160, 2017.

[2] K. N. Kumar and P. R. Balaramachandran, "Robotic process automation-a study of the impact on customer experience in retail banking industry," Journal of Internet Banking and Commerce, vol. 23, no. 3, pp. 1-27, 2018.

[3] A. Kyguolienė and N. Makutėnas, "Measuring gen-y customer experience in the banking sector," Management of Organizations: Systematic Research, vol. 78, no. 1, pp. 77-93, 2017.

[4] C. I. Mbama, P. Ezepue, L. Alboul, and M. Beer, "Digital banking, customer experience and financial performance: An international journal," Journal of Research in Interactive Marketing, vol. 12, no. 4, pp. 432-451, 2018.

[5] J. Kandampully, Z. Tingting, and E. Jaakkola, "Customer experience management in hospitality," International Journal of Contemporary Hospitality Management, vol. 30, no. 1, pp. 21-56, 2018.

[6] D. Sharma, "Enhancing customer experience using technological innovations: A study of the indian hotel industry," Worldwide Hospitality and Tourism Themes, vol. 8, no. 4, pp. 469-480, 2016.

[7] M. Veríssimo and N. Menezes, "Social media as a tool to enhance customer experience in hospitality industry," Revista Portuguesa de Marketing, vol. 38, no. 34, pp. 23-30, 2015.

[8] S. Shrivastava, "Digital disruption is redefining the customer experience: The digital transformation approach of the communications service providers," Telecom Business Review, vol. 10, no. 1, pp. 41-52, 2017.

[9] S. Joshi, "Enhancing customer experience: An exploratory study on the role of retailer as an effective touch-point for enhancing customer experience for cellular service providers," Drishtikon: A Management Journal, vol. 5, no. 1, pp. 88-100, 2013.

[10] J. C. Bustamante and N. Rubio, "Measuring customer experience in physical retail environments," Journal of Service Management, vol. 28, no. 5, pp. 884-913, 2017.

[11] M. Rodríguez, F. Paredes, and Y. Gaofeng, "Towards future customer experience: Trends and innovation in retail," Foresight and STI Governance, vol. 10, no. 3, pp. 18-28, 2016.

[12] H. Kumar, "Augmented reality in online retailing: A systematic review and research agenda," International Journal of Retail & Distribution Management, vol. 50, no. 4, pp. 537-559, 2022.

[13] S. Rose, N. Hair, and M. Clark, "Online customer experience: A review of the business - to - consumer online purchase context," International Journal of Management Reviews, vol. 13, no. 1, pp. 24-39, 2011.

[14] A. M. Fawcett, S. E. Fawcett, M. B. Cooper, and K. S. Daynes, "Moments of angst: A critical incident approach to designing customer-experience value systems," Benchmarking, vol. 21, no. 3, pp. 450-480, 2014.

[15] J. Chepur and R. Bellamkonda, "Examining the conceptualizations of customer experience as a construct," Academy of Marketing Studies Journal, vol. 23, no. 1, pp. 1-9, 2019.

[16] R. T. R. Varma, "Enhancing and empowering: Customer experience," SCMS Journal of Indian Management, vol. 9, no. 3, pp. 71-78, 2012.

[17] J. Machala and D. Havíř, "You cannot do it yourself: Enhancing experience through co-creation," Trendy Ekonomiky a Managementu, vol. 13, no. 33, pp. 51-57, 2019.

[18] M. Stone, "The death of personal service: Will financial services customers who serve themselves do better than if they are served?," Journal of Database Marketing & Customer Strategy Management, vol. 19, no. 2, pp. 107-119, 2012.

[19] M. Rishi, A. Singh, and R. Shukla, "Confluence of technology and commercial factors at iskcon temple: Reflections on customer experience," Worldwide Hospitality and Tourism Themes, vol. 2, no. 5, pp. 539-553, 2010.

[20] F. Buttle and S. Maklan, *Customer relationship management: Concepts and technologies*. Routledge, 2019.

[21] B. J. Pine and J. H. Gilmore, "Welcome to the experience economy," Harvard business review, vol. 76, pp. 97-105, 1998.

[22] R. Jain, J. Aagja, and S. Bagdare, "Customer experience–a review and research agenda," Journal of Service Theory and Practice, vol. 27, no. 3, pp. 642-662, 2017.

[23] C. Homburg, D. Jozić, and C. Kuehnl, "Customer experience management: Toward implementing an evolving marketing concept," Journal of the Academy of Marketing Science, vol. 45, no. 3, pp. 377-401, 2017.

[24] L. Du Plessis and M. De Vries, "Towards a holistic customer experience management framework for enterprises," South African Journal of Industrial Engineering, vol. 27, no. 3, pp. 23-36, 2016.

[25] S. Rahimian, M. ShamiZanjani, A. Manian, and E. Mohammad Rahim, "A framework of customer experience management for hotel industry," International Journal of Contemporary Hospitality Management, vol. 33, no. 5, pp. 1413-1436, 2021.

[26] H. Yen-Hao and S.-T. Yuan, "An application of technology-based design for exhibition services," International Journal of Quality and Service Sciences, vol. 8, no. 4, pp. 498-515, 2016.

[27] R. N. Bolton, J. R. McColl-Kennedy, L. Cheung, A. Gallan, C. Orsingher, L. Witell *et al.*, "Customer experience challenges: Bringing together digital, physical and social realms," Journal of Service Management, vol. 29, no. 5, pp. 776-808, 2018.

[28] M. M. Batra, "Designing a holistic customer experience program," Competition Forum, vol. 16, no. 1, pp. 73-81, 2018.

[29] M. M. Batra, "Customer experience: Trends, challenges, and managerial issues," Journal of Competitiveness Studies, vol. 27, no. 2, pp. 138-151, 2019.

[30] D. Siriguppi and J. Nair, "Tata aia life leverages digital technologies to create a superior customer experience," IUP Journal of Marketing Management, vol. 20, no. 4, pp. 400-411, 2021.

[31] M. M. Batra, "Strengthening customer experience through artificial intelligence: An upcoming trend," Competition Forum, vol. 17, no. 2, pp. 223-231, 2019.

[32] I. R. Hodgkinson, T. W. Jackson, and A. A. West, "Customer experience management: Asking the right questions," The Journal of Business Strategy, vol. 43, no. 2, pp. 105-114, 2022.

[33] H. O. S. Jorge, G. H. S. Mendes, P. A. Cauchick Miguel, M. Amorim, and T. Jorge Grenha, "Customer experience research: Intellectual structure and future research opportunities," Journal of Service Theory and Practice, vol. 31, no. 6, pp. 893-931, 2021.

[34] B. Neuhofer, B. Magnus, and K. Celuch, "The impact of artificial intelligence on event experiences: A scenario technique approach," Electronic Markets, vol. 31, no. 3, pp. 601-617, 2021.

[35] I. Anica-Popa, L. Anica-Popa, C. Rădulescu, and M. Vrîncianu, "The integration of artificial intelligence in retail: Benefits, challenges and a dedicated conceptual framework," Amfiteatru Economic, vol. 23, no. 56, pp. 120-136, 2021.

[36] S. Bharwani and D. Mathews, "Techno-business strategies for enhancing guest experience in luxury hotels: A managerial perspective," Worldwide Hospitality and Tourism Themes, vol. 13, no. 2, pp. 168-185, 2021.

[37] M. Dini, S. Splendiani, L. Bravi, and P. Tonino, "In-store technologies to improve customer experience and interaction: An exploratory investigation in italian travel agencies," TQM Journal, vol. 34, no. 7, pp. 94-114, 2022.

[38] H. Tseng-Lung, S. Mathews, and C. Y. Chou, "Enhancing online rapport experience via augmented reality," The Journal of Services Marketing, vol. 33, no. 7, pp. 851-865, 2019.

[39] R. Chen, P. Perry, R. Boardman, and H. McCormick, "Augmented reality in retail: A systematic review of research foci and future research agenda," International Journal of Retail & Distribution Management, vol. 50, no. 4, pp. 498-518, 2022.

[40] T. Hilken, J. Heller, M. Chylinski, D. I. Keeling, D. Mahr, and R. Ko de, "Making omnichannel an augmented reality: The current and future state of the art: An international journal," Journal of Research in Interactive Marketing, vol. 12, no. 4, pp. 509-523, 2018.

[41] M. Kozina and D. Dusper, "Adopting best practices to improve customer experience management," 62nd International Scientific Conference on Economic and Social Development, pp. 288-295, 2020.

[42] S. S. Liu and J. Chen, "Using data mining to segment healthcare markets from patients' preference perspectives," International Journal of Health Care Quality Assurance, vol. 22, no. 2, pp. 117-34, 2009.

[43] J. Dawes and J. Rowley, "Enhancing the customer experience: Contributions from information technology," Management Decision, vol. 36, no. 5, pp. 350-357, 1998.

[44] C. Ja-Shen, Y. L. Tran-Thien, and F. Devina, "Usability and responsiveness of artificial intelligence chatbot on online customer experience in e-retailing," International Journal of Retail & Distribution Management, vol. 49, no. 11, pp. 1512-1531, 2021.

[45] K. Sidaoui, M. Jaakkola, and J. Burton, "Ai feel you: Customer experience assessment via chatbot interviews," Journal of Service Management, vol. 31, no. 4, pp. 745-766, 2020.

 ISBN: 978-1-68558-051-3

[46] I. Lubbe and N. Ngoma, "Useful chatbot experience provides technological satisfaction: An emerging market perspective," South African Journal of Information Management, vol. 23, no. 1, pp. 1-8, 2021.

[47] A. Abdulquadri, E. Mogaji, T. A. Kieu, and N. Nguyen Phong, "Digital transformation in financial services provision: A nigerian perspective to the adoption of chatbot," Journal of Enterprising Communities, vol. 15, no. 2, pp. 258-281, 2021.

[48] P. Kumar, A. K. Mokha, and S. C. Pattnaik, "Electronic customer relationship management (e-crm), customer experience and customer satisfaction: Evidence from the banking industry," Benchmarking, vol. 29, no. 2, pp. 551-572, 2022.

[49] J. Teixeira, L. Patrício, N. J. Nunes, L. Nóbrega, R. P. Fisk, and L. Constantine, "Customer experience modeling: From customer experience to service design," Journal of Service Management, vol. 23, no. 3, pp. 362-376, 2012.

[50] G. Timokhina, L. Prokopova, Y. Gribanov, S. Zaitsev, N. Ivashkova, R. Sidorchuk *et al.*, "Digital customer experience mapping in russian premium banking," Economies, vol. 9, no. 3, pp. 1-24, 2021.

[51] A. Ludwiczak, "Using customer journey mapping to improve public services: A critical analysis of the literature," Management, vol. 25, no. 2, pp. 22-35, 2021.

[52] A. Lao, M. Vlad, and A. Martin, "Exploring how digital kiosk customer experience enhances shopping value, self-mental imagery and behavioral responses," International Journal of Retail & Distribution Management, vol. 49, no. 7, pp. 817-845, 2021.

[53] Y. Vakulenko, D. Hellström, and P. Oghazi, "Customer value in self-service kiosks: A systematic literature review," International Journal of Retail & Distribution Management, vol. 46, no. 5, pp. 507-527, 2018.

[54] Z. Sander Paul and A. Farhoomand, "The hong kong jockey club: Transforming customer experience through information technology," Communications of the Association for Information Systems, vol. 34, pp. 1115-1132, 2014.

[55] C. Gellweiler and L. Krishnamurthi, "Editorial: How digital innovators achieve customer value," Journal of Theoretical and Applied Electronic Commerce Research, vol. 15, no. 1, pp. I-VIII, 2020.

[56] V. Vitezic, T. Car, and M. Simunic, "Managing innovative technology in the hotel industry - response to growing consumer preferences," Tourism in Southern and Eastern Europe, vol. 3, pp. 467-478, 2015.

[57] R. Tateson and E. Bonsma, "Shoppinggarden -- improving the customer experience with on-line catalogues," BT Technology Journal, vol. 21, no. 4, pp. 84-91, 2003.

[58] S. Barat, "Rfid – improving the customer experience," The Journal of Consumer Marketing, vol. 28, no. 4, pp. 316-317, 2011.

[59] K. N. Kumar and P. R. Balaramachandran, "Robotic process automation - a study of the impact on customer experience in retail banking industry," Journal of Internet Banking and Commerce, vol. 23, no. 3, pp. 1-27, 2018.

[60] M. Åkesson, B. Edvardsson, and B. Tronvoll, "Customer experience from a self-service system perspective," Journal of Service Management, vol. 25, no. 5, pp. 677-698, 2014.

[61] T. Chellapalli, "Customer experience of banking self-service technologies in india′s an empirical study," Academy of Marketing Studies Journal, vol. 27, no. 3, pp. 666-675, 2023.

[62] C. Lu, W. Geng, and I. Wang, "The role of self-service mobile technologies in the creation of customer travel experiences," Technology Innovation Management Review, vol. 5, no. 2, pp. 24-32, 2015.

[63] M. Stone, "The death of personal service: Why retailers make consumers responsible for their own customer experience," Journal of Database Marketing & Customer Strategy Management, vol. 18, no. 4, pp. 233-239, 2011.

[64] L. Gonçalves, L. Patrício, T. Jorge Grenha, and N. V. Wünderlich, "Understanding the customer experience with smart services," Journal of Service Management, vol. 31, no. 4, pp. 723-744, 2020.

[65] S. Kabadayi, F. Ali, H. Choi, H. Joosten, and C. Lu, "Smart service experience in hospitality and tourism services: A conceptualization and future research agenda," Journal of Service Management, vol. 30, no. 3, pp. 326-348, 2019.

[66] S. K. Tewari, "Information technology: A tool to drive customer experience," Academy of Marketing Studies Journal, suppl. Special Issue 1, vol. 26, pp. 1-14, 2022.

[67] U. Ramanathan, N. Subramanian, and G. Parrott, "Role of social media in retail network operations and marketing to enhance customer satisfaction," International Journal of Operations & Production Management, vol. 37, no. 1, pp. 105-123, 2017.

[68] Z. Tingting, J. Kandampully, and A. Bilgihan, "Motivations for customer engagement in online co-innovation communities (occs)," Journal of Hospitality and Tourism Technology, vol. 6, no. 3, pp. 311-328, 2015.

[69] P. Echeverri, "Video-based methodology: Capturing real-time perceptions of customer processes," International Journal of Service Industry Management, vol. 16, no. 2, pp. 199-209, 2005.

[70] M. Simoni, A. Sorrentino, D. Leone, and A. Caporuscio, "Boosting the pre-purchase experience through virtual reality. Insights from the cruise industry," Journal of Hospitality and Tourism Technology, vol. 13, no. 1, pp. 140-156, 2022.

[71] T. Stevens and A. May, "Improving customer experience using web services," BT Technology Journal, vol. 22, no. 1, pp. 63-71, 2004.

Strategic Agility of an Incumbent Firm and Chief Digital Officer in the Face of Digital Innovation: A Microfoundation Approach

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***Abstract*—In today's business environment, strategic agility is critical for large firms, as it enables continuous adjustment of the firm's strategic direction, promoting value creation. In this context, some firms have decided to immerse employees in external startups to accelerate their digital initiatives. The greater flexibility of this startup thus enables it to imagine innovative digital products and services. This paper proposes that the skills/competencies of the parent firm's Chief Digital Officer (CDO) – the executive who oversees the startup's digital initiatives – positively influence the firm's strategic agility. Drawing on the dynamic capabilities approach and microeconomic foundations, the model aims to provide a new perspective on the CDO's contribution when large companies create external startups to meet the digital transformation challenges.**

Keywords-strategic agility; microfoundations; Chief Digital Officer (CDO); startup; digital innovation and transformation.

I. INTRODUCTION

In today's competitive, volatile, and uncertain business environments, digital transformation has become a crucial strategic priority for large firms [1]. Digital technologies, such as multi-sided platforms, mobile applications, big data analytics, Internet of Things (IoT), and artificial intelligence are generating fundamentally new business opportunities, fostering digital innovations with distinctive characteristics [2][3], with the potential to disrupt traditional businesses [1].

To meet the digital transformation challenges and accelerate their digitalization via continuous and sustainable innovation [4], large firms have built innovation capabilities in digital technologies by connecting with startup ecosystems [5]. These global firms have adopted a variety of strategies: intrapreneurship, setting up startup incubators/accelerators, open innovation, investments and equity ownership, and startup acquisitions [6]. Recently, a new innovation strategy, called *excubation*, has been adopted by these firms in the face of startups, which aims to have some employees work outside the company in an accelerator, to explore innovation ideas in a limited time frame [7][8]. Startup excubation aims to create a new entity, independent from the parent company, in the form of a startup focused on digital innovations [7] and is considered as a powerful growth driver [8].

The steering of digital innovation initiatives led by this startup is generally entrusted to an executive and member of the firm's Top Management Team (TMT). In large firms, the choice of this executive is dictated by the nature and scope of the digital innovation strategy, its relationship to corporate strategy [9], and the value and skills/competencies that this manager brings [10][11]. The management of the startup's innovations can be entrusted to one of the firm's executives, whose choice may depend on the firm's digital strategy. If the strategy is focused on technology, this executive could be the Chief Information Officer (CIO) or the Chief Technology Officer (CTO) ; if the digital strategy is focused on data management, it could be the Chief Data Officer (CDO) ; if the focus is on company-wide innovation, it could be the Chief Innovation Officer (CINO) or the CDO, who oversees the firm's digital innovation and transformation. Typically, the CDO leads the excubated startup, while the startup's ability to successfully develop and bring digital innovations to market reflects the incumbent firm's strategic agility [12].

In these large firms, the CDO is involved in the digital innovation management process [13][14]. Since the position emerged in the 2000s, practitioners and IS researchers have studied the CDO phenomenon [13][14]. Prior studies have identified the impacts of CDO skills and competencies on the digital transformation of traditional firms [15][16] by studying different types of CDO roles [13]-[16], desirable skills [17], the nature of digital leadership [18], and dimensions of CDO leadership [14]. The firm expects the CDO, through their distinctive skills, to positively influence the startup's ability to successfully commercialize digital innovations, reflecting a form of strategic agility of the firm.

Strategic agility has been identified as a key success factor for companies [19][20]. Strategic agility represents the company's ability to constantly adjust its strategic axes to changing and uncertain environments to deploy innovative methods of value creation [19]. Through a combination of dynamic capabilities (strategic sensitivity, resource fluidity and collective commitment) [19][20], strategic agility refers to the ability to act quickly to anticipate change and seize opportunities. It is critical for traditional firms driving their digital transformation, due to the rapid and unpredictable disruptions associated with digital technologies [21].

Yet, despite the useful results of these studies, it remains unclear why it is relevant to focus on the impact of CDO skills and competencies when it comes to the successful commercialization of digital innovations carried by large firms. One reason is that these studies provide a fragmented picture of the CDO, with the impact of the CDO being studied only through a few aspects, such as types of roles [15]-[17], the personal, professional, business, and technical competencies targeted [18], or the organizational design of the CDO role [14]. Moreover, few studies have focussed on how or under what conditions individual factors (microfoundations) contribute to or support the go-to-market routines of digital innovations that, in turn, lead to strategic agility for firms that have created an excubated startup to address the challenges of their digital transformation [22]. This contrasts with large companies that have chosen more traditional ways of managing innovation. For example, the CDO who drives innovation in the excubated startup must enrich their skills/competencies to succeed in this mission, as strategic agility is more necessary in this context than when the firm has adopted traditional innovation management.

Drawing on the microfoundations perspective [23][24] and the dynamic capabilities approach [25][26], we seek to investigate the individual microfoundations of the CDO responsible for digital innovation of an excubated startup of a large firm and the relationship with the strategic agility of that firm. Our objective is to offer a theoretical perspective to better understand the microfoundations of strategic agility of pre-digital firms. The research question addressed is: *How do the skills of the CDO (individual microfoundations) influence the strategic agility of an incumbent firm, when it has chosen to create an excubated startup to successfully introduce digital innovations to the market?*

The rest of this paper is organized as follows. In Section II, we discuss the theories that are mobilized by conducting a literature review to develop our model. In Section III, we present the model and proposals. In Section IV, we discuss the contributions and implications for theory and practice, identify limitations and avenues for future research.

II. Theoretical Background

In this section, we review the literature upon which our conceptual model relies, i.e., literature on the creation of excubated startups by incumbent firms, on the CDO's roles and distinctive skills in large companies, as well as on strategic agility through the microfoundation approach.

A. *Creation of Excubated Startups by Incumbent Firms*

In order to seize the business opportunities brought about by digital transformation, several large firms whose success was built during the pre-digital economy [1], have decided to create external startups focused on digital innovations, in order to compete with the leaders in their industry [7][8].

This *excubation* strategy aims to create a new entity, autonomous and independent from the parent company, in the form of a startup dedicated to the development and commercialization of digital innovations [8]. According to Géméto et al. [8], excubation "*consists in immersing the employees of large companies in external startup accelerators in order to explore new business opportunities. Situated between intrapreneurship and open innovation, excubation offers rich lessons on the conditions necessary for large companies to succeed in their innovations but also to transform themselves into more agile organizations*". It aims to offer a more effective alternative to traditional approaches to innovation management [7][8], such as the development of internal innovation capabilities with intrapreneurship; cooperation with open innovation models [27] or partnership programs via incubators or accelerators, external or internal labs; minority investments in startups, partnerships or via investment funds; and the acquisition of majority stakes, the buyout, or the acquisition of startups [7].

However, these approaches have several limitations [28]. First, intrapreneurial projects do not always succeed, due to the lack of managers' entrepreneurial mindset designated by the large firm and turned intrapreneurs, limited by the internal constraints and the organizational culture of the company that deprive them of agility. The use of external entrepreneurs recruited to lead these intrapreneurial projects is not much more successful than with internal managers, for the same reasons, they find it difficult to adapt to the constraints of large firms and suffer from a lack of support from the TMT [4]. Second, collaborative approaches based on open innovation and partnerships between large firms and startups are limited by divergent or hardly compatible strategies, goals, interests, and cultures. Several studies have examined startups that view such collaboration as mere window dressing, allowing large firms to communicate their ability to innovate and their agility, rather than leveraging cooperation and making it a powerful engine of growth [5][6]. Moreover, incubators, accelerators, labs/fablabs, may suffer from a lack of critical size and real resources to ensure their development [6]. Furthermore, the "corporate ventures" investment approach [5][6] is difficult to implement, as it requires investing large sums of money to obtain a 15% to 20% stake in startups without having control over them, which limits their growth potential. Finally, the process of buying or acquiring successful startups requires significant investments, even more so for technology startups, as well the integration of the startup's managers and teams into the company's structure and culture remains problematic [5].

As a result, excubation, allows employees of a large firm to work outside the firm in an external startup accelerator to explore an innovation opportunity [7]. Excubation aims to address the limitations of usual approaches by combining the strength of the large company with the organizational agility of the startup [8]. For large corporations that have adopted excubation, the benefits are numerous [8]. Examples include better alignment between the firm innovation goals and the startup's ability to develop and commercialize innovations, the startup's vocation to act as a growth engine for the parent company [5], the operational speed made possible by a team mastering rapid development methods, while freeing itself from the constraints and administrative procedures of the parent company, in order to grow faster [29].

More specifically, the excubation of startups has at least two benefits for a large firm. The first is that the firm's CDO, whose additional mission is to oversee the startup's digital innovation projects, should have a positive influence on the success of the projects, especially because of their skills [30].

The second benefit is the company's increased strategic agility, not only because of the startup's flexible structure, but above all, because of the startup's superior ability to develop and commercialize digital innovations [12].

B. CDO's Roles and Distinctive Skills in Large Companies

In order to drive digital transformation, large firms have created a dedicated role within their TMT and appointed a Chief Digital Officer [13][32]. Since the mid-2000s, the widespread presence and growing influence of the CDO role has been an interesting phenomenon studied by researchers and practitioners alike [13]-[16][31][32]. These studies suggest that the decision to create a CDO position stems from the strategic nature of digital transformation, the urgency to drive it, and the need for coordination with other functions to define and deploy a digital strategy [21][31].

A review of the CDO literature (e.g., [13][14]) shows that the presence of the CDO in the strategy and operations of large firms can be explained in particular by the CDO's impact on firm performance [18]. This impact can take many forms: it can be positive tactical and operational outcomes related to maintaining or increasing the firm's innovation capabilities, improving customer engagement via big data analytics, or recognizing the strategic nature of the CDO role beyond expected responsibilities [16][31]. In contrast, other work suggests that the CDO role may be temporary ([14], p. 16), because it could disappear or merge with other roles.

This focus on the CDO emphasizes the importance of identifying and developing the skills/competencies expected of the role. Several recent studies have proposed such skills and competencies, which have subsequently allowed for the elaboration of CDO role typologies and the characterization of the requirements and limitations of each type of CDO role [13][14]. This article also aims to explain the conditions for the emergence or antecedents of the presence of the CDO role, and the skills required to meet digital challenges [15].

The following are some examples of prior studies. Haffke et al. [13] identified four CDO roles: the *digital innovator*, who innovates on strategies and customer experience; the *digitization coordinator*, who manages transformation and monitors change initiatives; the *digital advocate*, who communicates change across business functions to facilitate cooperation; and the *digital evangelist*, who promotes the need for and benefits of digital transformation. In the same vein, Singh and Hess [14] identify three roles (*entrepreneur*, *digital evangelist*, *coordinator*) and five competencies (IT competency, change management skills, inspiration skills, digital pioneering skills, resilience). Tumbas et al [15][16] identify digital capabilities of successful CDOs, which are combinations of skills (digital innovation, data analytics, customer engagement) and three profiles of CDOs: *digital accelerator*, *digital marketer*, and *digital harmonizer*, each profile focusing on one of the digital capabilities. Finally, Tahvanainen and Luoma [17] identify four categories and 28 competencies (personal, professional, business, and technical competencies) and compare them to those of IT leaders. This study identified the CDO as also a *business developer* and *change agent*.

C. Strategic Agility through the Microfoundation Approach

Strategic agility is the ability of a firm to continuously adapt to changing contexts [19][20]. Work on strategic agility has been done in various streams of research [24], such as strategy, management, IS, innovation management, digital entrepreneurship, and among practitioners.

On the other hand, the dynamic capabilities perspective [23] [24] emphasizes how firms dynamically reconfigure their resources to generate new capabilities and respond to unpredictable changes in their environment. Teece [33] defines three dynamic capabilities: *sensing* capability, which aims to identify opportunities and threats; *seizing* capability, which aims to seize opportunities; *reconfiguring* capability, which aims to maintain competitiveness by enhancing, combining, and reconfiguring firm assets. Prior studies have used dynamic capabilities to inform the notion of agility, explaining the extent and speed with which firms perform reconfiguration of their resources [33][34]. Strategic agility is considered a meta-capability, a combination of capabilities [19][20][22]. Doz and Kosonen [19][20] posited that strategic agility is formed by three dimensions: *strategic sensitivity*, *resource fluidity*, and *collective commitment*.

However, despite the usefulness of these studies, the mechanisms at individual level by which a firm's strategic agility manifests itself have yet to be clarified. In particular, studies on innovation management, digital entrepreneurship, and startup creation by pre-digital firms [5]-[8] show that microfoundations emanating from the behaviors and skills of key individuals in startups are not well understood, because their contributions are aggregated to the organizational level of analysis and thus invisible [23]. It is therefore not possible to identify individual contributions. Microfoundations reflect individual actions that shape strategy and organization [24]. Teece [33] defines "*the microfoundations of dynamic capabilities – the distinct skills, processes, procedures, organizational structures, decision rules, and disciplines – which undergird enterprise-level sensing, seizing, and reconfiguring capacities are difficult to develop and deploy*" ([33], p. 1319). By focusing on microfoundations, we believe that the firm strategic agility lies on individuals, processes, and interactions, as well as context and structures to function [34]. As a result, studying agility beyond the organizational level of analysis should improve our understanding. In their review of the agility literature, Tallon et al [35] state that early conceptualizations of agility focused on the adaptation of the organization to the environment, meaning that the evolution of the organization depends on its ability to adapt to changes in its environment. The authors note that previous work on agility has focused on the organization as a unit of analysis, and little on individual factors, which would explain the challenge of identifying individual contribution.

III. Theory Development and Propositions

We mobilize the microfoundations perspective with the aim of advancing research on the strategic agility of large traditional firms. Our position is that the microfoundations allow us to extend our understanding of corporate strategic agility (macro-level phenomenon) with mechanisms that operate at a micro-level (individual microfoundations). More precisely, we mobilize Coleman's framework [36] to study

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the microfoundations of strategic agility. Indeed, Coleman suggested that a macro-level phenomenon (here, the strategic agility of large firms) can be explained by the aggregation of the actions of an individual actor (the firm's CDO). These actions, in turn, are determined by specific conditions related to the individual and are only slightly influenced by macro-level variables [36].

In what follows, we posit that these individual action conditions are represented by the CDO's skills. In line with Coleman's framework ("boat") [36], these conditions act as determinants of the microfoundations of strategic agility. Our model considers the actors of the startup's ecosystem, who interact through the CDO's skills (microfoundations), thus stimulating the firm's strategic agility [31][32]. Fig. 1 gives an overview of our model which we describe in this section.

A. CDO's Skills/Competencies and Strategic Agility

We theorize the relationship of the CDO, who drives the digital innovations of the excubated startup, through their skills/competencies, with the firm's strategic agility, which is represented by the startup's excubation. As mentioned in our literature review, the common thread of these studies lies in the distinctiveness of the CDO's skill/competencies. When large firms drive their digital transformation in a changing environment, the key skills of the CDO most decisive for success are those that contribute to the achievement of the role's main objectives [21][30][32], which can be broken down into three categories.

The first objective of the CDO is to develop and successfully implement the ***digital strategy***, which may result from merging the firm's business strategy with the IT strategy [3][21]. It should be noted that, depending on the digital goals set, the responsibility for driving the digital strategy may be assumed – in whole or in part – by a senior executive in the TMT other than the CDO. Indeed, the CIO could oversee the digital strategy if it is focused on the business value of technologies and their uses. It could be the CTO, if the focus is on IT infrastructure or platforms, the CINO, if the focus is on technological innovations, or the Chief Data Officer, if the focus is on data management. The Chief Marketing Officer (CMO) may also be a candidate if the digital strategy is focused on improving the customer engagement and experience [11]. Choosing the right senior executive to lead the company's digital strategy depends on the value and skills/competencies they can bring [10][17].

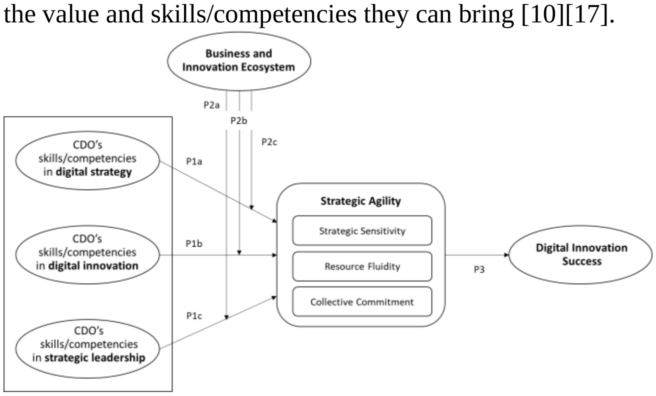

Figure 1. Proposed conceptual model.

The second objective of the CDO touches on the design, development, and commercialization of the startup's digital innovations, recognizing the nature of ***digital innovation***, conceptualized as "*the creation of (and consequent change in) market offerings, business processes, or models that result from the use of digital technology*" ([3], p. 224).

Finally, the third objective is related to the CDO's ability to provide ***strategic leadership***. The CDO's strategic leadership can be defined as the ability to convince internal decision makers and employees of the need to digitally transform and to demonstrate the benefits that will come from that transformation [14]. The literature on CDOs, like that on TMT, emphasizes the bottom-up nature of the managers' interactions with the line manager – in the case of the CDO, this is the CEO or COO in a large firm – and the top-down nature with the supervised teams – in the case of the CDO, these teams include the excubated startup's digital innovation management team [31][32]. As such, we posit that the unique CDO skills/competencies that can positively influence strategic agility focus on digital strategy direction, digital innovation management, and strategic leadership. The preceding discussion leads us to the following proposals:

P1a-1c: *The CDO (a) digital strategy, (b) digital innovation, and (c) strategic leadership skills are positively associated with the firm's strategic agility.*

B. The Moderating Effect of the Innovation Ecosystem

We theorize the relationship between the actors of the startup's business and innovation ecosystem and the CDO. To succeed, the CDO must maintain a close relationship with the ecosystem's actors in which the startup is immersed. The concept of business ecosystems was introduced in the 1990s by Moore [27][29] and refers to business networks that are formed beyond territorial limits, since cooperation between firms is on an international scale. The ecosystem refers to actors (organizations, firms, startups, universities, investors, resources, etc.) that interact to promote innovation.

Consequently, the CDO's responsibility is broadened: drawing on the CDO skills in digital strategy, digital innovation, and strategic leadership, they are led to play a role as facilitator between the firm, the excubated startup, and its ecosystem [7][8]. This relationship is essential, as the startup's ability to successfully design, prototype, develop, and commercialize digital innovations depends on the quality of its interactions with its ecosystem [27]. To the extent that the CDO plays a facilitating role with the ecosystem actors, it follows that the ecosystem exerts a positive influence on the relationship between the CDO represented by the three core skills/competencies and the firm strategic agility. The preceding discussion leads us to the following proposals:

P2a-2c: *The ecosystem in which the startup is immersed has a positive moderating effect on the relationship between (a) the CDO digital strategy skills and strategic agility; (b) the CDO digital innovation skills and strategic agility; and (c) the CDO strategic leadership skills and strategic agility.*

C. Strategic Agility and Digital Innovation Success

We theorize the relationship between the firm's strategic agility and the digital innovation go-to-market success. Like

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Doz and Kosonen [19][20], we conceptualize strategic agility along three dimensions (strategic sensitivity, resource fluidity, and collective commitment) and show that each dimension promotes innovation market success.

First, strategic sensitivity allows the firm to obtain useful information from its environment, detect opportunities and internal constraints according to strategic priorities, market, and competitive conditions [19]. Via strategic sensitivity, the firm is aware of capabilities, technologies, and processes useful for designing, developing, and launching innovations. By increasing its strategic sensitivity, the firm will identify unmet market needs and changes in its environment, which generates favorable conditions for developing and launching innovations [19][20]. Thus, we posit that strategic sensitivity exerts a positive impact on the successful commercialization of the excubated startup's innovations.

Second, resource fluidity, another dimension of strategic agility, supports effective management of the innovation portfolio. The ability to allocate and reallocate resources is critical to the development of innovations. When resource fluidity increases, internal processes become more flexible and easily modified [19]. As resources (financial, human, technological, etc.) become more mobile within the firm, greater flexibility is achieved, allowing for reorganization or redeployment of resources, and supporting strategic goals, such as driving digital transformation or managing a portfolio of innovations. Resource fluidity plays a key role in facilitating the process by which the group reassesses its innovation portfolio. Resource (re)allocation leads the firm to revise its cost and revenue structure, including that of the innovation portfolio, to reflect changing priorities [20]. Thus, we posit that resource fluidity exerts a positive influence on the market success of innovations managed by the startup.

Finally, collective commitment, refers to the managerial commitment of the company, which fosters organizational adaptation in the face of rapid and unexpected changes in the environment. Studies on dynamic capabilities suggest that when a new opportunity is perceived, management decisions must be made quickly to take advantage of that opportunity [19]. These collective management decisions are essential for internal changes aimed at innovation management processes [19]. Obtaining a collective commitment from the TMT, and in particular from the CDO, plays a central role in resolving conflicts and allows delicate situations to be resolved. As a result, we posit that collective commitment positively influences the success of bringing innovations managed by the startup to market. This leads us to the following proposal:

P3: *Strategic agility (i.e., strategic sensitivity, resource fluidity, collective commitment) is positively associated with the success of digital innovations managed by the startup excubated by a large incumbent firm.*

IV. DISCUSSION AND CONCLUSION

Digital transformation is causing radical changes in the way large firms do business. To stay in the race, some of them decide to excubate a startup, i.e., to create an external startup, involving its ecosystem and allocating resources to build a portfolio of innovations to bring them successfully to market. The CDO, who oversees the digital innovations of the excubated startup, plays a key role as his/her distinctive skills positively influence the firm strategic agility.

We propose a model of this phenomenon in which three types of CDO skills/competencies (in digital strategy, digital innovation, and strategic leadership) are microfoundations of strategic agility (strategic sensitivity, resource fluidity, and collective commitment). As well, strategic agility mediates the relationship between the CDO skills and the innovation go-to-market success. And we postulate that the ecosystem, which is critical to the growth of the startup, moderates the relationship between CDO skills and strategic agility.

We believe that this paper makes four contributions. First, we contribute to the study of microfoundations by conceptualizing the impact of the CDO skills (individual microfoundations) responsible for the digital innovations of an excubated startup on the strategic agility of a large firm leading a digital transformation. This contribution adds to the literature on the microfoundations of strategic agility [34], of large firms in the context of digital transformation. Second, by positing that the ecosystem in which the excubated startup is embedded plays moderating roles along microfoundations and dimensions of strategic agility, we emphasize the place of the ecosystem in the growth of startups. Third, we add insights to digital transformation research, in particular, on the relationship between dynamic capabilities and digital transformation [21]. We study the phenomenon from the perspective of CDOs involved in digital innovation. Prior studies have taken this approach to explain other digital transformation outcomes, such as the determinants of CDO performance [32] but neglecting strategic agility. Fourth, from a practical perspective, our model should be of interest to CDOs managing an innovation portfolio, as it highlights a new contribution of CDOs to innovation management.

We are aware that our model has limitations. First, it has only scratched the surface of the relation between strategic agility and microfoundations. A growing body of work focuses on the microfoundations of strategy [34], suggesting that researchers are looking at individual factors to explain phenomena at a more micro level. Second, we only included the skills/competencies of CDOs that reflect the goals of the role. More specific work needs to be done to identify a more general set of expected CDO skills in digital innovation.

Furthermore, our model provides a partial understanding of the CDO's role regarding digital innovation. Therefore, our model did not explore other themes related to the skills of the CDO, such as digital culture, strategic use of IT, firm's dynamic capabilities during a digital transformation, etc. We encourage future research into these relationships, which will provide more specific explanations of the role of the CDO. In addition, we chose the excubation approach, as it represents a strong trend among large firms [7]. Finally, as our objective was exclusively to develop a conceptual model, we chose not to test the model. The model could be tested by operationalizing the CDO's skills/competencies [17] through interviews with CDOs from different industries, following for example the approach taken by [14][15], who conducted semi-structured and exploratory interviews. We encourage future research to test and extend this model to clarify the impact of the CDO's role on digital innovation.

REFERENCES

[1] C. Klos, P. Spieth, T. Clauss, and C. Klusmann, “Digital transformation of incumbent firms: A business model innovation perspective,” IEEE Transactions on Engineering Management, vol. 70, no. 6, pp. 2017-2033, 2023.

[2] R. G. Fichman, B. L. Dos Santos, and Z. Zheng, “Digital innovation as a fundamental and powerful concept in the information systems curriculum,” MIS Quarterly, vol. 38, no. 2, pp. 329–A15, 2014.

[3] S. Nambisan, K. Lyytinen, A. Majchrzak, and M. Song, “Digital innovation management,” MIS Quarterly, vol. 41, no. 1, pp. 223-238, 2017.

[4] A. Braganza, Y. Awazu, and K. C. Desouza, “Sustaining innovation is challenge for incumbents,” Research-Technology Management, vol. 52, no. 4, pp. 46-56, 2009.

[5] A. Skala, Digital startups in transition economies. Challenges for management, entrepreneurship, and education. Cham, Switzerland: Palgrave Macmillan/Springer Nature, 2019.

[6] H. Zaheer, Y. Breyer, and J. Dumay, “Digital entrepreneurship: An interdisciplinary structured literature review and research agenda,” Technological Forecasting and Social Change, vol. 148, 119735, pp. 1-20, 2019.

[7] M. Géméto, D. Chabaud, and I. Barth, “Excuber pour innover : une nouvelle voie pour les grandes entreprises ?” Entreprendre & Innover, vol. 46, no. 3, pp. 30-41, 2020.

[8] M. Géméto and I. Barth, “L’excubation : vers une nouvelle gouvernance de l’innovation,” in La gouvernance dans tous ses états, M. Dufour et al., Eds. Paris: EMS Éditions, pp. 322-342, 2021.

[9] F. Svahn, L. Mathiassen, and R. Lindgren, “Embracing digital innovation in incumbent firms: How Volvo Cars managed competing concerns,” MIS Quarterly, vol 41, no. 1, pp. 239-254, 2017.

[10] A. Buchwald and F. Lorenz, “Who is in charge of digital transformation? The birth and rise of the Chief Digital Officer,” Academy of Management Proceedings, no. 1, 14317, pp. 1-33, 2020.

[11] J. Taylor and J. Vithayathil, “Who delivers the bigger bang for the buck: CMO or CIO?” The Journal of Strategic Information Systems, vol. 27, no. 3, pp. 207-220, 2018.

[12] N. Islam, P. Buxman, and N. Eling, “Why should incumbent firms jump on the start-up bandwagon in the digital era? A qualitative study,” Proc. der 13. Internationalen Tagung W. (WI 2017) St. Gallen, Switzerland, 2017, pp. 1378-1392.

[13] I. Haffke, B. Kalgovas, and A. Benlian, “The role of the CIO and the CDO in an organization’s digital transformation,” Proc. of the 37th International Conference on Information Systems (ICIS 2016), Dublin, Ireland, 2016, pp. 1-20.

[14] A. Singh and T. Hess, “How Chief Digital Officers promote the digital transformation of their companies,” MIS Quarterly Executive, vol 16, no. 1, pp. 1-17, 2017.

[15] S. Tumbas, N. Berente, and J. Brocke, “Three types of CDOs and the reasons organizations adopt the role,” MIS Quarterly Executive, vol. 16, no. 2, pp. 121-134, 2017.

[16] S. Tumbas, N. Berente, and J. vom Brocke, “Digital innovation and institutional entrepreneurship: Chief Digital Officer perspectives of their emerging role,” Journal of Information Technology, vol. 33, pp. 188-202, 2018.

[17] S. Tahvanainen and E. Luoma, “Examining the competencies of the CDO,” Proc. of 24th Americas Conference on Information Systems (ACIS 2018), 2018, pp. 1-10.

[18] J. A. Porfírio, T. Carrilho, J. A. Felício, and J. Jardim, “Leadership characteristics and digital transformation,” Journal of Business Research, vol. 124, pp. 610-619, 2021.

[19] Y. Doz and M. Kosonen, Fast strategy: How strategic agility will help you stay ahead of the game. Harlow, GB: Wharton School Publishing/Pearson Education, 2008.

[20] Y. Doz, “Fostering strategic agility: How individual executives and human resource practices contribute,” Human Resource Management Review, vol. 30, pp. 1-14, 2020.

[21] G. Vial, “Understanding digital transformation: A review and a research agenda,” The Journal of Strategic Information Systems, vol. 28, no. 2, pp. 118-144, 2019.

[22] S. Bresciani, A. Ferraris, M. Romano, and G. Santoro, “Agility for successful digital transformation,” in Digital transformation management for agile organizations: A compass to sail the digital world, S. Bresciani et al., Eds. Emerald Publishing Limited, pp. 167-187, 2021.

[23] P. Abell, T. Felin, and N. Foss, “Building micro-foundations for the routines, capabilities, and performance links,” Managerial and Decision Economics, vol. 29, no. 6, pp. 489-502, 2008.

[24] T. Felin and N. Foss, “Strategic organization: A field in search of micro-foundations,” Strategic Organization, vol. 3, no. 4, pp. 441-455, 2005.

[25] R. Adner and C. E. Helfat, “Corporate effects and dynamic managerial capabilities,” Strategic Management Journal, vol. 24, no. 10, pp. 1011-1025, 2003.

[26] C. E. Helfat and M. A. Peteraf, “Managerial cognitive capabilities and the microfoundations of dynamic capabilities,” Strategic Management Journal, vol. 36, no. 6, pp. 831-850, 2015.

[27] H. W. Chesbrough, Open innovation. The new imperative for creating and profiting from technology. Boston, MA: Harvard Business School Press, 2003.

[28] W. R. Carter and G. A. Jackson, “Clockspeed, competition, and cooperation: incumbent motives and the market for ideas,” Journal of Small Business & Entrepreneurship, vol. 32, no. 3, pp. 241-264, 2020.

[29] E. Ries, The lean startup: How today’s entrepreneurs use continuous innovation to create radically successful businesses. New York, NY: Crown Business, 2011.

[30] J. Berbel-Vera, M. B. Palanca, and M. B. Gonzalez-Sanchez, “Key CDO functions for successful digital transformation: Insights from a Delphi study,” Technological Forecasting and Social Change, vol. 181, 121773, pp. 1-16, 2022.

[31] S. Firk, A. Hanelt, J. Oehmichen, and M. Wolff, “CDOs: An analysis of the presence of a centralized digital transformation role”, Journal of Management Studies, vol. 58, no. 7, pp. 1800-1831, 2021.

[32] S. Kunisch, M. Menz, and R. Langan, “CDOs: an exploratory analysis of their emergence, nature, and determinants,” Long Range Planning, vol. 55, pp. 1-18, 2022.

[33] D. J. Teece, “Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance,” Strategic Management Journal, vol. 28, no. 13, pp. 1319-1350, 2007.

[34] N. Foss, “Microfoundations in strategy: Content, current status and future prospects,” in Strategic management: State of the field and its future, M. Duhaime et al., Eds. Oxford University Press, pp. 559-577, 2021.

[35] P. P. Tallon, M. Queiroz, T. Coltman, and R. Sharma, “Information technology and the search for organizational agility: A systematic review with future research possibilities,” The Journal of Strategic Information Systems, vol. 28, no. 2, pp. 218-237, 2019.

[36] C. Crick and E. K Chew, “Microfoundations of organizational agility: a socio-technical perspective,” Communications of the Association for Information Systems, vol. 46, paper 12, pp. 273-295, 2020.