VR-EvoEA+BP: Using Virtual Reality to Visualize Enterprise Context Dynamics Related to Enterprise Evolution and Business Processes

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Abstract. Enterprise digitalization results in an evolving and dynamic IT landscape of digital elements, relations, knowledge, content, activities, and business processes (BPs), which are spread across disparate enterprise IT systems, repositories, and tools. To be relevant, useful, and actionable, Enterprise Architecture (EA) relies on comprehensive documentation based on underlying information corresponding to reality. Yet current diagram-centric 2D visualizations for EA and BP models are too limited in scope to express reality (intentionally simplifying), are typically static (and not kept up-to-date), and cannot express and integrate the changing complexities of the enterprise context. This misalignment with reality and a changing enterprise misinforms and constrains the context-awareness and perception of EA and BP for stakeholders, impeding analyses, management, and holistic insights into the enterprise digital reality. This paper contributes our nexus-based Virtual Reality (VR) solution concept VR-EvoEA+BP to support comprehensive enterprise context visualization in conjunction with EA and model evolution and BP mining and analysis. Portraying an organic, evolving, and dynamic enterprise while supplementing static enterprise structure depictions, our implementation demonstrates its feasibility. A case study based on enterprise analysis and BP scenarios exhibits its potential.

Keywords: Virtual Reality, Enterprise Architecture, Business Processes, Context-Awareness, Enterprise Evolution, Process Mining, Enterprise Architecture Management, Enterprise Modeling, Visualization.

1 Introduction

"Everything moves on and nothing is at rest," ascribed by Plato to Heraclitus [1] and reformulated by others in numerous ways, expresses change as the only constant. What is assumed to be stable and static in our perceived (enterprise) reality is often not, particularly the complex digital reality on which today's enterprises rely, which necessarily evolves and adapts to market and technological disruptions. This may be especially true for Enterprise Architecture (EA), which comprises the structural and behavioral aspects needed for an enterprise to function and adapt in alignment with some vision. Hence, EA seeks to provide a comprehensive set of cohesive models describing the enterprise structure and functions, while logically arranging individual models to provide further detail about an enterprise [2]. Yet digitalization implies a growing set of digital elements, relations, and associated IT complexity, with EA information spanning disparate silos of repositories across organizations and systems. Operationally, BPs represent the structured activities of an organization towards achieving its business goals, and their execution represent a critical part of the dynamics of an enterprise. In particular, EA evolution and business processes (BPs) are key dynamic aspects of a "living" enterprise, and their visualization, especially concomitantly with their associated enterprise context, presents a challenge.

Many EA methods and diagrams assume static structures, yet the underlying digital reality an EA attempts to depict is increasingly dynamic. EA representations are an enterprise asset that must be governed [3], yet the effort required to maintain architectural views that are current is very high in organizations [4]. This is primarily due to the organization's structure being the result of an asynchronous, distributed, and heterogeneous process, producing representations in various languages and notations, at different levels of detail, and with different tools at different timepoints. Furthermore, current, EA and BP models are not readily accessible to all enterprise citizens or stakeholder groups, hindering the ability to exploit "grassroots modeling" [5] and ensure the validity, practicality, and optimization of EA or BP models. Furthermore, due to their lack of capability to visualize the enterprise reality, EA Management (EAM) methods and tools oversimplify and cannot convey the real associated enterprise context for any representation. Yet as enterprises evolve, explicit knowledge of and insight into the EA becomes indispensable for enterprise governance, compliance, maintenance, etc. Thus, for correct model perception, a valid and accurate depiction and comprehension of enterprise context is vital, yet not feasible with current EAM methods and tools. Moreover, inaccurate or missing context depiction impairs EA comprehension, resulting in misguided EA-related decisions and additional risk.

To address these challenges, the unlimited space of Virtual Reality (VR) could be leveraged to visualize an enterprise's digital reality as well as the context surrounding enterprise elements, while providing an immersive experience accessible to hitherto excluded stakeholder groups. In support of using VR, Müller et al. [6] investigated VR vs. 2D for a software analysis task, finding that VR did not significantly decrease comprehension and analysis time, yet improved the user experience, being more motivating, less demanding, more inventive/innovative, and more clearly structured. In our view, VR could similarly benefit EAM without incurring significant liabilities.

Our VR-related prior work includes VR-EAT [7] for dynamically-generated Atlas EA diagrams; VR-BPMN [8] for Business Process Model and Notation (BPMN) [9]; VR-ProcessMine [10]; and VR-EA+TCK [11], which integrates EA tool, Knowledge Management Systems (KMS), and Enterprise Content Management System (ECMS) capabilities. This paper describes VR-EvoEA+BP, our nexus-based VR solution concept, which contributes an enterprise context-enhanced visualization of 1) enterprise model evolution, and 2) mined BP and BP variant execution dynamics. An organic, evolving, and dynamic enterprise can be holistically portrayed with each element's context and relations, while supplementing further enterprise structure and content depiction (such as diagrams and media). Our implementation demonstrates its feasibility, while a case study exhibits its potential based on enterprise analysis scenarios.

This paper is structured as follows: Section 2 discusses related work while Section 3 provides background on Atlas. Our solution concept is described in Section 4. Section 5 details our prototype implementation. The evaluation is described in Section 6, followed by a conclusion.

2 Related Work

EA visualization work in the area of XR includes Rehring et al. [12], who posit from literature that VR or Mixed Reality (MR) offer affordances that can positively influence EAM decision-making quality and effectiveness. Rehring et al. [13] concluded that EAM with Augmented Reality (AR) can improve EA comprehension. The survey of EA visualization tools by Roth et al. [14] makes no mention of XR or VR, nor does the systematic review by Jugel [15]. Non-XR EA visualization work includes Naranjo et al. [16], who describe PRIMate, a 2D graph-based enterprise analysis framework containing a graph, treemap, and 3D visualization of an the archiSurance ArchiMate model [17]. Rehring et al. [18] used an 3D city metaphor to conceptualize an EA using districts for EA analysis scenarios and streets for processes. Work related to visualizing EA evolution includes Roth & Matthes [19], who use a 2D multi-layer interactive drill down paradigm to visualize EA model differences. Atlas [4][20] includes EA evolution visualization support using a 2D browser (our solution integrates Atlas to support our VR-based evolution visualization). Beyond our own prior work, we are unaware of work applying VR to the EA area, specifically integrating EA tools, multi-EA-diagram support, heterogenous EA models (ArchiMate, BPMN, UML), ECMS and KMS integration, and a nexus-based visualization.

As to BP visualization in conjunction with enterprise context, the systematic literature review by Dani et al. [21] mentions techniques that augment BP models with additional information, yet context is not explicitly mentioned, with the only XR work mentioned being our own VR-BPMN [8]. AR approaches integrating enterprise context with BPs include: our own (as global context) [22][23], Muff & Fill [24], and Grum & Gronau [25]. As to context-awareness support in BPM methods, Denner et al. [2622] assessed the degree of context-awareness in extant BPM methods, finding: support for goal exploration rare; very few methods account for process, organization, and environment dimensions; and the process dimension seldom supports the context factors knowledge-intensity, creativity, interdependence, and variability. As to BP variant analysis techniques in the area of process mining, the survey by Taymouri et al. [27] found the area fragmented, and while certain visualization techniques were discussed, no XR techniques are mentioned. Our previous work VR-ProcessMine [10] visualizes BP variants and enactments in VR, but lacks an enterprise context. In contrast, VR-EvoEA+BP: depicts BPs and their mined processes in their entire enterprise context comprehensively, showing holistic relations to roles, people, and other relevant enterprise elements; visualizes BP variants; enables stepping through a BP variant or trace sequentially with complete enterprise context; augments any BP activity with additional real content, documentation, and knowledge; and depicts Atlas-generated (current and non-stale) BPMN model diagrams in 3D in VR.

3 Background on the EA Tool Atlas

Atlas is an enterprise cartography solution [4][20][28] that can support fast-changing organizations, creating and maintaining up-to-date architectural models and views spanning a large set of view types (see Fig. 1). Offering a fully configurable meta-model with a consolidated repository, it dynamically generates fully configurable views that can depict any timepoint with each element shown in its corresponding lifecycle state. It minimizes the effort to produce consolidated architectural views relative to any timepoint and the evolution of an architecture over time can be viewed.

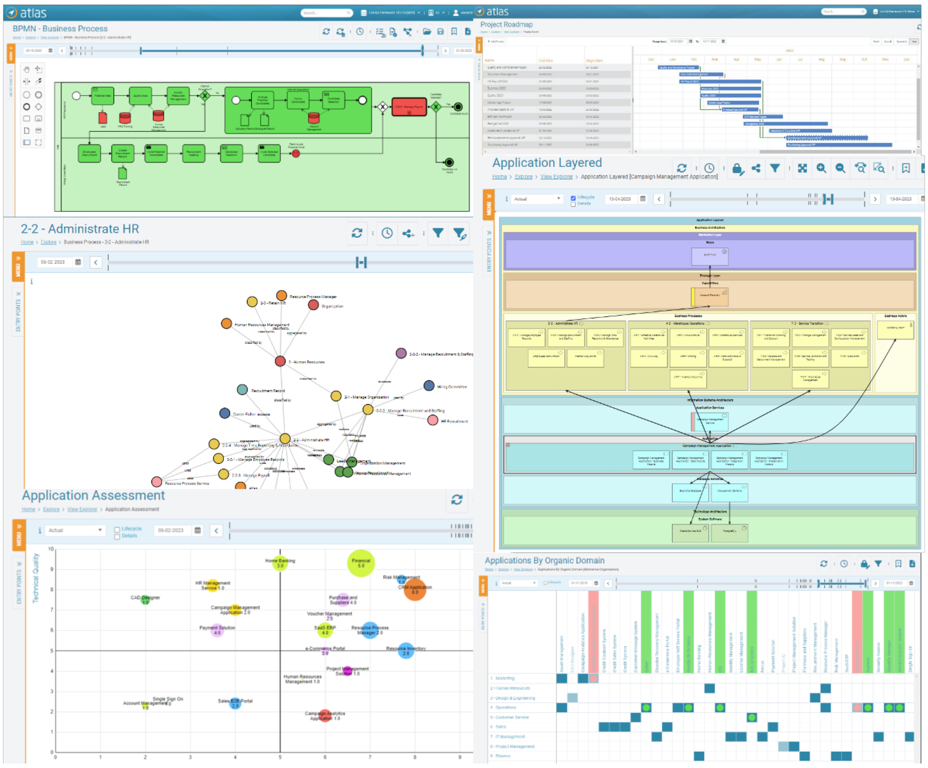

Fig. 1. Example dynamically generated diagram types supported by Atlas.

Support for temporal navigation and gap analysis is a unique feature of Atlas and, in our experience, fundamental to reducing the effort of maintaining architectural views in large organizations. In Atlas, all views have a time bar that allows the view contents to change according to the time bar position, from the past to the future. A view can depict the gap analysis between any two dates, as presented in the application organic view in Fig. 2. Elements marked with red are in production today but will be decommissioned at the future date. Elements marked in green are planned to be in production at a future date, while the those in yellow are expected to remain in production but changed in structure between the two dates.

Atlas also supports generated views of BPMN models as shown in the upper left in Fig. 1. As with all views, a unique feature of Atlas is its ability to generate and support temporal navigation in these views also. The BPMN design canvas is built on top of the BPMN.IO library to support the graphical aspects of BPMN. However, the semantics of each BPMN symbol remains configurable, allowing different mappings against the metamodel, each of which is also user-configurable. For example, in an Atlas metamodel referencing The Open Group Architecture Framework (TOGAF) Content Metamodel (CMM) [29], one BPMN canvas may map a “data object” to be an “Entity” in the metamodel, while in another BPMN canvas the “data object” could be mapped against a “Logical Data Component” concept in the metamodel. This is one example where Atlas supports different stakeholder communities to keep their “way-of-modeling,” while mapping different models into to a single global model.

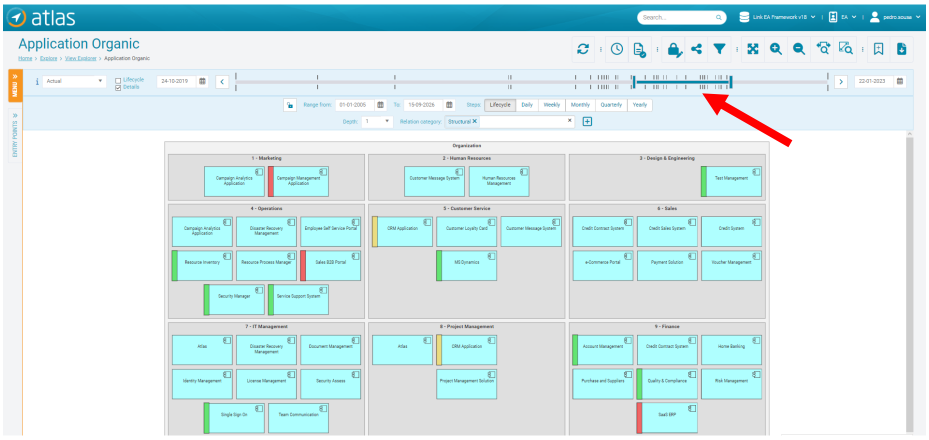

Fig. 2. Application landscape view in Atlas showing time bar gap analysis (red arrow).

With ArchiMate [17], supported by Atlas, this different “ways-of-modeling” problem is by far more common and complex than for BPMN. This is due not only to the much larger set of concepts, but also because the notation has evolved significantly from version 1.0 to version 3.2, requiring support for importing models from different ArchiMate versions. For example, if the user configures the relationships of the type "is responsible for" and "uses" between an actor and a component application in the Atlas metamodel, when importing an Archimate models that contains relationships between actors and applications (having a different set of relation types between actors and applications), it should configure mapping the rules between them. This mapping can be defined in each instantiation of the drawing canvas.

The possibility to configure and instantiate multiple design canvases, each with a specialized mapping with the Atlas defined metamodel, enables mapping different ontologies for provisioning and viewing within the organization. Given the multiple and different internal views the different communities have of their organization, the external view plays a very significant role, and it stands as an independent view, against whom internal communities map their models and ontologies.

To mitigate the complexity of managing different architectural models, Atlas also supports modeling gap analysis, indicating what is common and distinctive to each model set. E.g., the gap between applications (modeled as an applications store) can be viewed in business-owned BPMN models, while IT uses its application catalog.

4 Solution Concept

Our solution approach leverages the unlimited space VR offers for visualizing the growing and complex set of EA models and their interrelationships simultaneously in a spatial structure. Furthermore, besides unlimited visualization, the VR environment provides an ability to immersively "experience" EA to explore and comprehend the "big picture" for structurally and hierarchically complex and interconnected models, diagrams, content, documentation, and digital elements in a 3D space viewable from different perspectives by various stakeholders with heterogeneous interests.

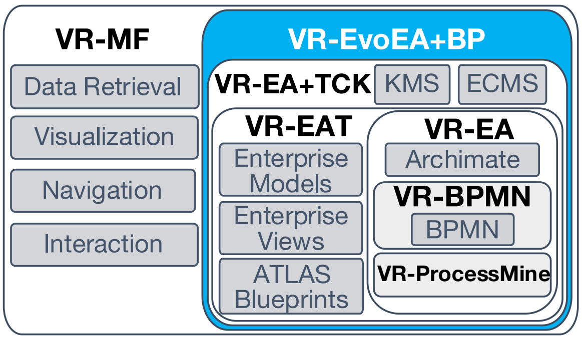

Fig. 3. Solution concept map showing VR-EvoEA+BP (blue) in relation to other concepts.

Since EA is a broad topic with many facets, we have developed various solutions concepts, a map of which is shown in Fig. 3. Our generalized VR Modeling Framework (VR-MF), described in [30], provides a domain-independent hypermodeling framework addressing key aspects for modeling in VR: visualization, navigation, interaction, and data retrieval. Using this, VR-EA [30] provides specialized direct support and mapping for EA models in VR, including both ArchiMate as well as BPMN via VR-BPMN [8]. VR-ProcessMine [10] supports process mining in VR. VR-EAT [7] extends this to our enterprise repository integration solution, exemplified with Atlas integration, visualization of IT blueprints, and interaction capabilities. VR-EA+TCK [11] expands this further, integrating KMS and ECMS capabilities in VR.

Having this EA foundation for static models, diagrams, knowledge, and content is one thing, but how do we make EA "come alive"? We thus developed our solution concept VR-EvoEA+BP for expressing and conveying the "living enterprise," which, in our opinion, offers a vast set of possible scenarios and potential. To capture our intent and demonstrate the concept concretely, two scenarios where chosen that, in particular, provide for visualizing and experiencing EA *in conjunction with contextual dynamics*: 1) enterprise evolution / change / adaptation, explicitly bringing and visualizing the dimension of time into VR space, and 2) contextualized BP execution, leveraging process mining (or simulation) to not just see theoretical BP models, but comprehending and experiencing BP dynamics operationally in the enterprise with all their associated context. To achieve these objectives, our solution concept necessitates enterprise data integration and VR visualization, navigation, and interaction capabilities, which are addressed as follows:

Enterprise data integration. As a representative EA tool and repository, Atlas provides access to diverse EA-related data in a coherent repository and meta-model and is not restricted to certain standards or notations. VR-EAT details our integration with Atlas. Atlas blueprints (diagrams) are necessarily limited in scope to address some stakeholder concern, which is necessary and helpful for stakeholders to avoid information overload. Yet the larger picture of the entire digital enterprise and all of its elements and relations cannot be easily conveyed via such single 2D diagram views. Furthermore, second degree relations and elements (beyond the diagram) or not readily perceived. Thus, certain insights or missing elements, relations, or aspects may not be readily detected. Furthermore, any models retained in a repository are typically limited in scope to that repository, and inter-repository relations (such as between Atlas and an ECMS or KMS, addressed via VR-EA+TCK [7]) are usually not obvious or discovered.

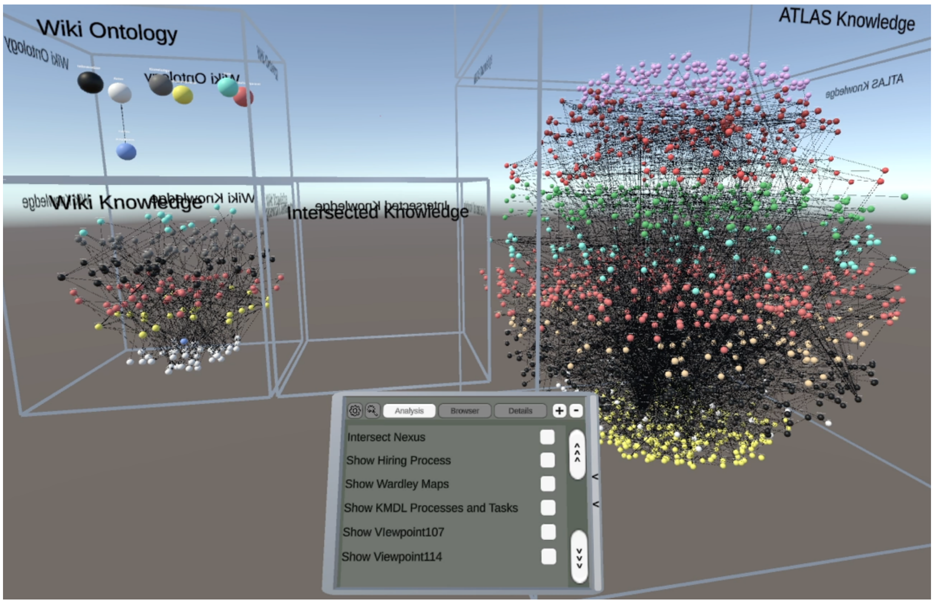

Fig. 4. VR-EvoEA+BP showing Atlas EA nexus (right), Semantic MediaWiki nexus (left), and VR-Tablet (foreground) in Analysis mode.

Visualization. As there are many possible relations between digital elements, a spherical nexus was chosen to visualize all elements and relations in a repository (see Fig. 4). To provide some initial ordering, layering within the sphere is available as a grouping mechanism based on similar element types using the color assigned to that type, resulting in a sphere with colored layers (intra-layer element placement is random). The default (customizable) node color scheme is loosely based on KMDL® [31], e.g., actor {white}, role {yellow}, information object {red}, task/conversion {green}, knowledge object {pink/purple}, requirement {orange}. To assist with orientation and make interaction more intuitive by providing a context for what a model represents, labeled glass boxes readable from any angle contain a nexus based on the model of a repository (ECMS, KMS). To show inter-relations between nexuses or models, we found directly drawn additional lines between nexus spheres to lead to a large crisscross of associations, making analysis difficult. A dynamically-generated nexus can show the intersection between nexus models (see [7]). As 2D-based views and diagrams remain a primary form of EA documentation, they are visualized (such as those from the EAT Atlas) as 3D hyperplanes in proximity to its nexus for contextual support. In summary, intangible digital elements or digital twins are made visible and related to one another across the enterprise spectrum.

Navigation. To support immersive navigation in VR while reducing the likelihood of potential VR sickness symptoms, two navigation modes are supported in the solution concept: the default uses gliding controls, enabling users to fly through the VR space and get an overview of the entire model from any angle they wish. Alternatively, teleporting permits a user to select a destination and be instantly placed there (i.e., moving the camera to that position), potentially reducing the probability of VR sickness when moving through a virtual space.

Interaction. Interaction in VR is supported primarily via the VR controllers and our VR-Tablet concept. Views consisting of diagrams (blueprints in Atlas terminology) stacked as hyperplanes, with corresponding objects highlighted in the Nexus or diagram with the other object is selected. Our VR-Tablet paradigm provides: interaction support, detailed information regarding a selected element, browser-based multimedia content, browsing, filtering, and searching for nexus nodes. For time-machine-like interaction and navigation, a timepoint slider is offered on the VR-Tablet that correspondingly adjusts the visualization to that timepoint.

5 Realization

The logical architecture used by our realization of VR-EvoEA+BP is shown in Fig. 5. Our foundational VR modeling framework VR-MF addresses visualization, navigation, interaction, and data integration, and realization aspects and details are described below.

Enterprise data integration. The Data Hub (Fig. 5 center) is based on .NET and provides data integration, data storage via MongoDB 5 as BSON (shown at the bottom), with data retrieval via JSON. Atlas integration (Fig. 5 top left) is cloud-based, including repository data and service access via REST queries, which retrieves Atlas blueprint diagram data as JSON. Data is loaded into the Data Hub is saved to MongoDB as BSON based on an internal schema format that enables us to transform and annotate the data as needed for VR. A command line extension (Fig. 5 left) provides helper functions for configuration, mapping, and data loading for the Data Hub. For demonstrating ECMS/KMS integration, the Semantic MediaWiki (SMW) (shown on the bottom right, purple) was integrated, consisting of MediaWiki with PHP and SMW within a Docker container, and with MariaDB running in a separate container. The MediaWiki Ontology is exported via the SWW script dumpRDF and parsed with dotNetRDF. Further multi-model integration – independent of the Data Hub and direct with Unity – is shown (upper right, green,), and includes ArchiMate (VR-EA) and BPMN (VR-BPMN).

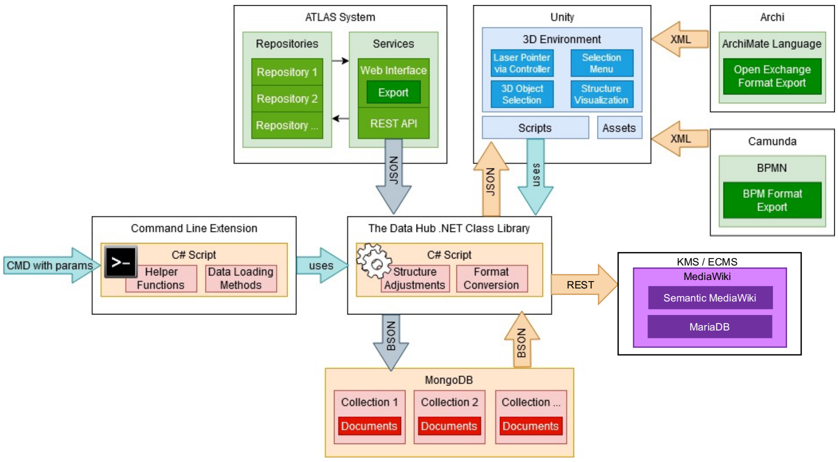

Fig. 5. Logical architecture. Source: [11] ©2022, Springer, reprinted with permission.

Visualization. VR-MF uses Unity (Fig. 5 top center) with the OpenVR XR Plugin. For digital element type and relational analysis support in VR, a glass meta-layer above any nexus represents all node types as spheres, with the type differentiated by color, and size conveying the relative number of instances (largest having most). Selecting a type at the meta-layer indicates all instances of that type within the nexus via a glow, while ghosting all non-related nodes. Selecting an element instance in a nexus highlights its corresponding type at the meta-layer, while first-degree neighbors and relations remain visible and all other elements are ghosted to reduce visual distractions (by unselecting, all become visible again).

To support evolution visualization in the nexus, colored glows represent the object state at a selected timepoint (Fig. 6). Following the color scheme of the legend for lifecycles in Atlas, elements marked with a red glow are in production at the chosen timepoint, but will be decommissioned at some future date. Elements marked in green are planned to be in production at a future date, while the those in yellow are expected to remain in production but changed in structure between the two dates. Since it would be trivial to provide a second button on the slider to support time gap analysis, it was deferred to focus on BP capabilities.

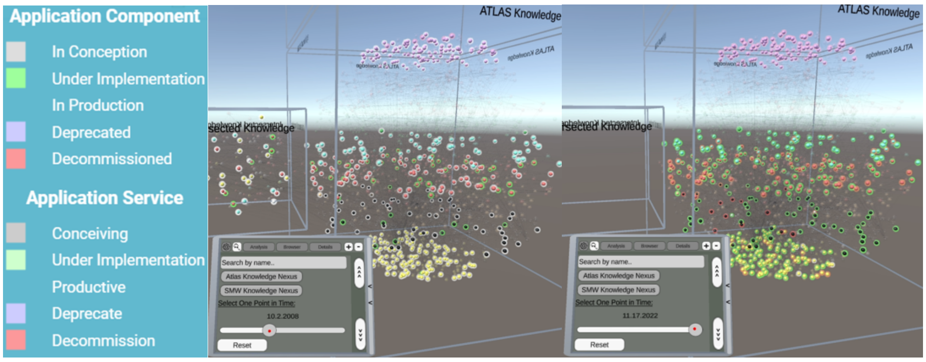

Fig. 6. Atlas timepoint lifecycle state legend (left) with correspondingly colored halos shown in the Nexus for 2008 (center) and 2022 (right).

Interaction. For evolution support, a timepoint slider was integrated on the VR-Tablet (Fig. 6) that enables timepoint interaction and navigation, adjusting the VR visualization accordingly. To support unified interaction between Atlas diagrams and the nexus in VR, a blueprint diagram stack is positioned in proximity to the nexus. If an element on a blueprint is selected, that corresponding node in the nexus is highlighted and the rest are ghosted, while the dynamic blueprint stack on the right is updated to show all blueprints that include that element. If all elements in a blueprint are selected, then all nodes in the nexus are highlighted with a different colored glow and the rest are ghosted. Besides supporting interaction, the VR-Tablet provides details about a selected nexus or diagram object. In Browser Mode, if the object has associated content, knowledge, or a web address (e.g, wiki), the VR-Tablet dynamically displays the content, exemplified in Fig. 13.

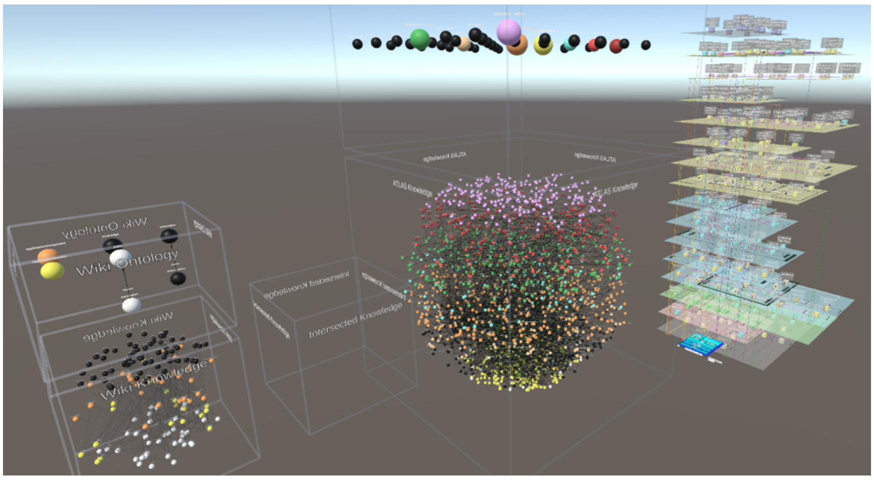

Fig. 7. Heterogeneous multi-model visualization and analysis: ECMS/KMS Wiki Knowledge Nexus (left), EA Atlas Nexus (center), Atlas Blueprint (right bottom, blue), and the ArchiSurance Archimate model (far right). Source: [11] ©2022, Springer, reprinted with permission.

Multi-model analysis. Immersive heterogeneous multi-model analysis can be supported by loading multiple models in VR. This is depicted in Fig. 7, where a ECMS/KMS Wiki Knowledge Nexus, an EA Atlas Nexus, one Atlas Blueprint, and an ArchiSurance Archimate model is shown.

6 Evaluation

For the evaluation of our solution concept, we refer to the design science method and principles [32], in particular, a viable artifact, problem relevance, and design evaluation (utility, quality, efficacy). To evaluate the practicality of the VR-EvoEA+BP solution concept and realization, a case study is used focusing on support for two illustrative analysis scenarios related to conveying the dynamics of enterprises: 1) an Enterprise Evolution Scenario, and 2) a Business Process, Variants, and Process Mining Scenario.

Enterprise data is highly sensitive, from a competitive, business, regulatory, and security standpoint among others. Thus, we relied on a simulated base. The enterprise data consisted of an Atlas repository that contained 66 sample core blueprints, and, via parameter choices, is capable of generating 7843 different blueprints diagrams across all selection combinations. This results in a total of 2034 nodes (unique entity instances) in the Atlas nexus, with 43 types and 2357 intra-nexus relations between element instances.

6.1 Enterprise Evolution Scenario

Our evolution scenario focuses on visualizing enterprise change over time for a stakeholder while offering element and relational context. While one knows enterprises evolve, it is difficult to comprehensively describe exactly what changed when, since often scarce comprehensive visualization capabilities regarding enterprise evolution in EA tools, especially since Atlas uniquely provides this support but not at a full visualization level. What exactly is evolving how over time, from the past to the present, and from the present to the future, and not at an overly abstract level or just a single diagram context, but with regard to the enterprise in its entirety, i.e., all enterprise objects. This limitation is partially a result of 2D modeling lacking a viable diagram type with sufficient granularity and visual space to comprehensively convey the enterprise at any given timepoint. If a specific context is known and diagrams obvious, Atlas uniquely offers lifecycle state and time gap analysis on a per diagram basis (see Section 2), which we incorporate in VR via our blueprint diagram stack.

To address a comprehensive evolution view, our nexus visualization concept leverages VR to depict in a condensed space all known enterprise objects and their relations at once, while capable of hiding objects and relations of no interest. Since Atlas retains the timepoint state of all objects, we utilized this data for our Nexus to convey the enterprise evolution at the full Nexus scale as shown in Fig. 8. Notice that in 2008 (see a and b) many nodes (e.g., meta-layer at the top of the Nexus and throughout) have a white halo (representing “in conception”), whereas in 2022 (see c and d), most nodes have a green halo (representing “in production”). In 2022 some nodes have a red halo representing “decommissioned” (seen in d). All ghosted nodes and relations had no associated timepoint state data, so, as their state at any given timepoint is unknown, they were ghosted (ghosting can be toggled). Hence, an animated evolution of the enterprise from the past to the planned future can be visualized using the time slider, while holistically depicting the enterprise context around an element. While our focus here was visualizing evolution, a separate nexus-centric time-gap analysis is also readily feasible by including an additional reference timepoint on the slider.

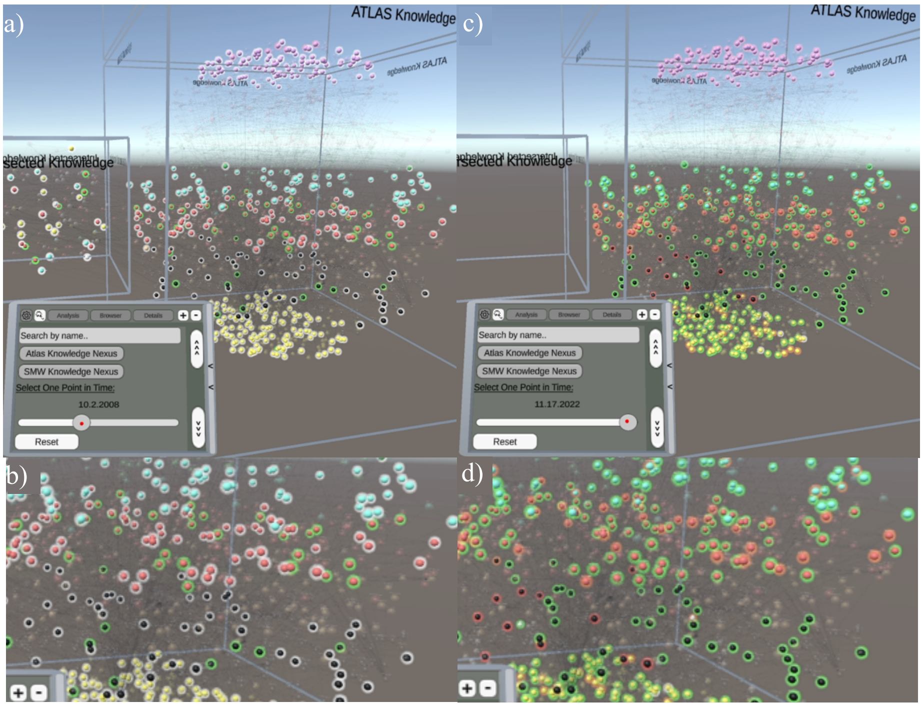

Fig. 8. Nexus object states as colored halos at timepoints: a) 2008 (top left) and b) enlargement (bottom left), and c) 2022 (top right) and d) enlargement of 2022 (bottom right).

In summary, a time-machine-like immersive enterprise time transport becomes viable for EA, allowing stakeholders to “move” to any timepoint in the past or the future of the enterprise, (since our visualization controls what is depicted and can be perceived). Dynamically moving the slider allows one to see an animated “movie” of the evolution of the enterprise.

6.2 Business Process, Variants, and Process Mining Scenario

As automation, efficiency, and productivity pressures increase, analyzing business processes (BP) becomes critical for enterprises. This includes assessing the activities involved in a BP, the sequencing of these activities, and the BP variants that occur during process enactment. For the BP evaluation scenario we used a Hiring Process example from our Atlas repository, depicted as seen in Atlas as a generated blueprint in Fig. 9 and modeled in BPMN in Fig. 10. The VR equivalent Atlas blueprint diagram is shown in Fig. 11 with the Atlas Nexus visible nearby on the left.

To provide sufficient trace and variant data, BP and BP variant simulation data was generated, since we did not receive permission to use actual enterprise process data. Following the event log XES file structure of 'running-example.xes' from the Process Mining book material [33], a Hiring Process.xes was manually created based on the Atlas Hiring Process structure. This XES file (see Fig. 12) was then processed by Process Mining for Python (pm4py) [34], generating a variants.json file and a dfg.json (Directly Follows Graph or DFG), wherein roles were manually incorporated to identify the responsible role for an activity. The files were then imported into our Data Hub.

Fig. 9. Hiring Process as depicted in Atlas as a generated blueprint.

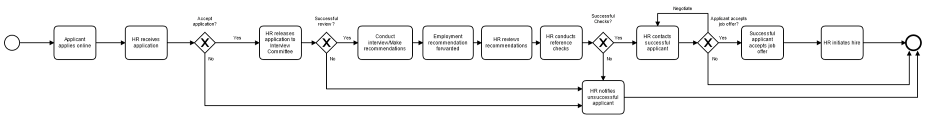

Fig. 10. Hiring Process modeled in BPMN.

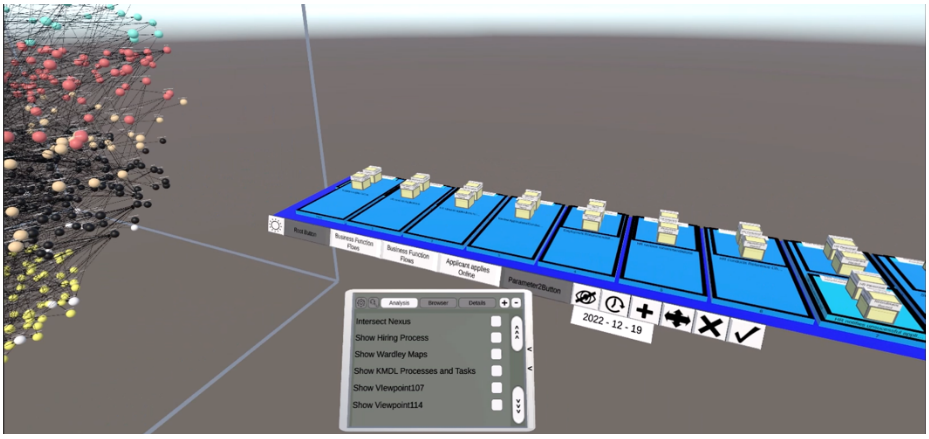

Fig. 11. VR-EvoEA+BP Hiring Process as a VR Atlas blueprint (right) with Atlas Nexus (left).

As shown in Fig. 13, Browser mode on the VR-Tablet offers context-specific content (e.g., browser, multimedia) for an associated node or process. In Analysis mode, selecting the Hiring Process highlights the involved nodes and connections in the Atlas Nexus, while ghosting all other nodes and connections. Start and end nodes are explicitly labeled as such to help with process navigation. Connections are annotated with their total number of occurrences in BP logs. For variant analysis, selecting a variant in the VR-Tablet highlights those nodes and connections with a colored glow (see Fig. 14). Automated navigation of that BP variant is supported via the VR-Tablet; a play button automates fly-through navigation to the next sequential node following the connection trace; a pause permits the user to stop the automation; and step back and forward buttons are provided as well. Further event details for a specific trace within a variant could be accessed via the VR-Tablet in Browser mode.


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    <event>
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      <string key="org:resource" value="Pete"/>
      <int key="@@index" value="14"/>
    </event>
    <event>
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    <event>
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    </event>
```


Fig. 12. Snippet from the Hiring Process XES file.

Besides BP variant analysis support, VR-EvoEA+BP provides additional contextual information for BP. E.g., below the BP graph white nodes can be seen (Fig. 14), which are associated roles and people involved in the BP activities. Fig. 15 provides a closeup, a left node representing the Hiring Committee and a node on the right the Interview Committee, whereby committee member names are seen in the foreground. This can help with responsibility and authority determination with regard to BPs, and from there, additional contextual analysis spanning BPs and enterprise areas could be considered, since BPs are embedded within the entire enterprise.

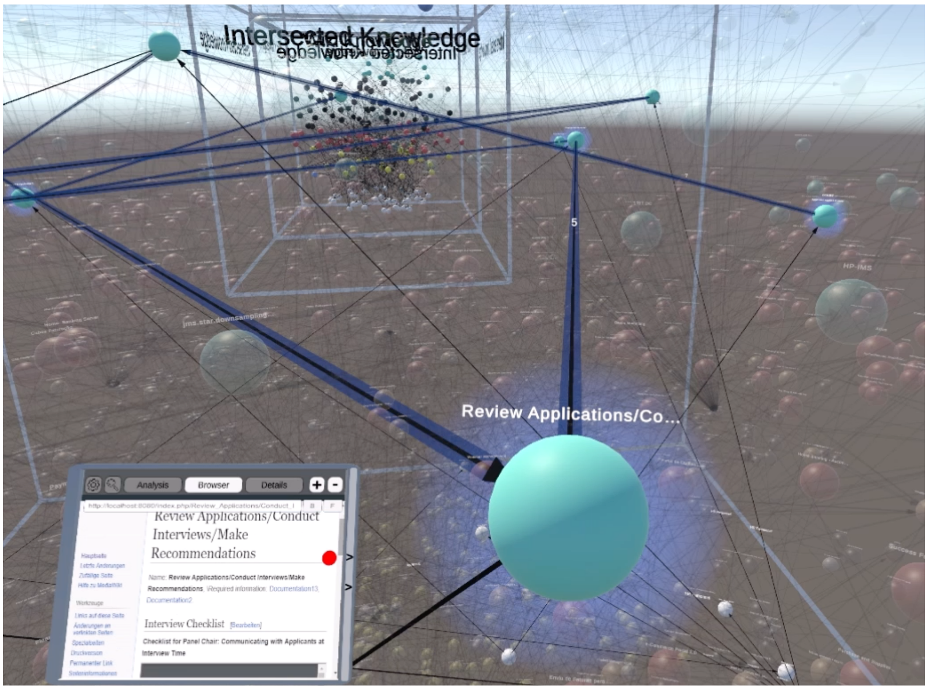

Fig. 13. BP activities and connections highlighted as nodes and relations in the Atlas Nexus; VR-Tablet shows content; associated roles can be seen as the small white nodes bottom right.

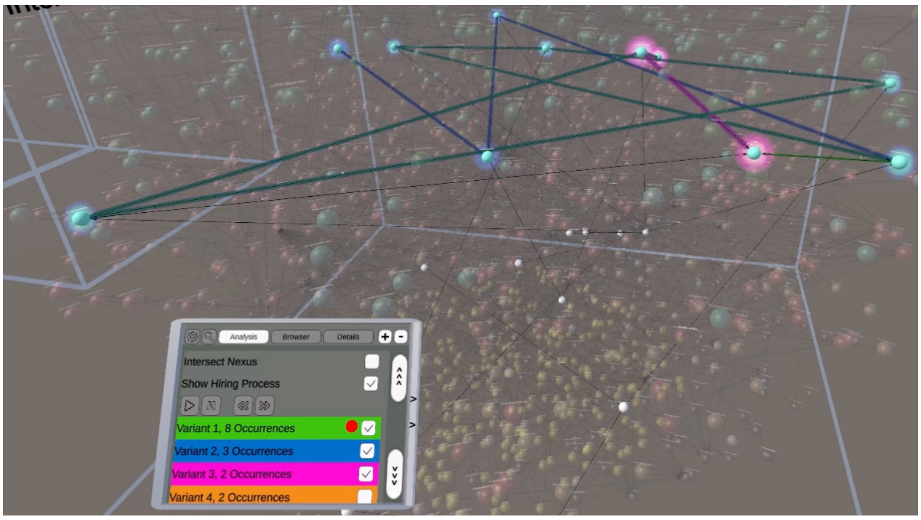

Fig. 14. Selecting any BP variant adds its color halo to its subset of nodes and connections.

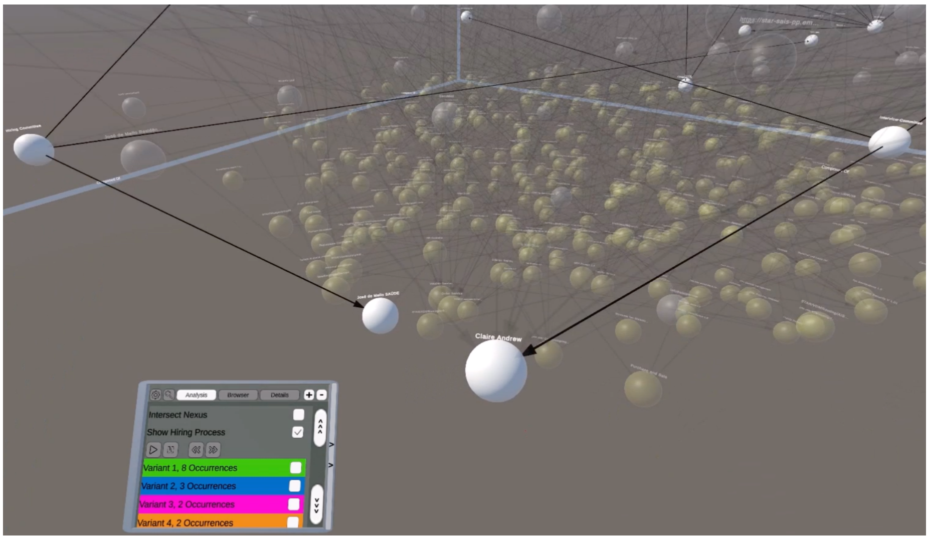

Fig. 15. Closeup of roles and people associated with BP activities in the Atlas Nexus (here Hiring Committee, Interview Committee members).

BP contextualization. BPs can be considered the heart of an enterprise. VR-EvoEA+BP supports the contextual integration of related knowledge or enterprise content (e.g., documentation, checklists, training videos, etc.) with a BP activity. This is often missing and not "experienced" when stakeholders view or analyze BP models or perform process mining related tasks. Furthermore, BP analysis can contextually combine the other analyses described in more detail in VR-EA+TCK [11], such as the ECMS/KMS coverage analysis, knowledge chain analysis, Wardley Map value chain analysis, and risk and governance analysis, ensuring that these important BPs consider all relevant aspects. By explicitly showing all elements, a stakeholder could potentially determine what is missing, what is desirable, what should be adapted in the enterprise structure, or what has become irrelevant and should be removed. These aspects might potentially be buried deep within certain diagrams and not be otherwise perceived without the comprehensive, holistic visualization offered by VR-EvoEA+BP.

7 Conclusion

Comprehensive visualization of the dynamics of enterprises, exhibited primarily in the evolution (both past and planned future changes) of the EA as well as the activities structured and executed in their BPs, enables the digital reality of enterprise to be perceived. The growing scale and complexity of the IT landscape makes VR an ideal medium for scaling beyond single EA diagrams to depict the associated enterprise context. VR-EvoEA+BP contributes a unique nexus-based VR visualization solution concept, providing comprehensive integration, visualization, and synthesis of heterogenous enterprise entities and their relations, models, and diagrams together with their enterprise context. Related enterprise knowledge and content is accessible via the browser-capable VR-Tablet. Our implementation demonstrated its feasibility, while the evaluation case study showed its potential to incorporate enterprise context in practical EAM analysis scenarios, specifically: evolution, time, and gap analysis between timepoints (past to the future planned states), as well as BP model, process mining, BP variant, and BP trace support. With our VR solution concept, EAM activities including analysis, discovery, inquiry, reasoning, decision-making, synthesis, and assessment becomes accessible for additional stakeholder groups to support inclusive "grass-roots modeling" with the associated validation and optimization benefits.

Future work includes enhancing the interactive, informational, analytical, and modeling capabilities of VR-EvoEA+BP, including force-directed layout, additional visualization alternatives, and a comprehensive empirical study.

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