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Virtual Reconstruction and Digital Twin of the Royal Monastery of San Benito of Sahagún: A Strategy for the Documentation, Conservation, and Dissemination of Lost Heritage

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Abstract

The virtual reconstruction of lost heritage ensembles has become an essential tool for the research, conservation, and dissemination of cultural heritage. This paper presents the application of advanced digital methodologies—terrestrial and aerial photogrammetry, 3D laser scanning, and 3D modeling using Blender—to the Royal Monastery of San Benito of Sahagún (León, Spain), one of the principal centers of Cluniac monasticism on the Iberian Peninsula. Through an interdisciplinary approach, a rigorous digital model has been developed that integrates historical, documentary, and geometric sources, enabling a substantiated restitution of the architectural configuration of the complex. The results highlight the potential of digital technologies not only for the restitution of lost volumetric structures but also as a basis for preventive conservation strategies, academic research, and the creation of immersive experiences aimed at both specialist and general audiences, thereby contributing significantly to the heritage valorization of the site.

CCS Concepts
· Computing methodologies → 3D modeling; 3D imaging; Photogrammetry
· Applied computing → Cultural heritage; Virtual reality; Digital preservation; Document scanning, 3D scanning

1. Introduction

The digitization of architectural heritage is a fundamental tool for documentation, conservation, and generation of historical and architectural knowledge. The virtual restitution of lost ensembles enables the development of cultural dissemination strategies and the promotion of cultural and rural tourism, particularly relevant in contexts where material heritage has suffered significant deterioration.

The Royal Monastery of San Benito of Sahagún played a crucial role in the consolidation of Benedictine monasticism on the Iberian Peninsula, now representing a paradigmatic case of lost architectural heritage. Despite its historical significance, much of the complex was destroyed following the 19th-century disentailment, complicating comprehensive architectural analysis.

This article presents a methodological proposal for its virtual reconstruction, based on the combined use of historical sources, geometric documentation technologies, and 3D modeling environments. The work not only recovers a substantiated hypothetical image of the monastery but also explores new avenues for preventive conservation, interdisciplinary research, and heritage dissemination through digital means.

2. Background

The Royal Monastery of San Benito in Sahagún stands as one of the most significant examples of Benedictine monasticism on the Iberian Peninsula. Founded in the 9th century and re-established in the late 11th century under royal patronage, it was among the first centers in Spain to adopt the Cluniac reform, integrating it into Cluny's international network and introducing architectural, liturgical, and organizational practices that transformed the monastic landscape of Europe during the 11th and 12th centuries.

Throughout its history, the complex underwent multiple transformations reflecting the evolution of architectural styles, from Romanesque to Baroque. Notably, the monastic church, whose final configuration is attributed to Pedro de la Torre, stands as one of the most monumental expressions of Leonese Baroque. However, the 19th-century disentailment led to the ruin of much of the complex.

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Currently, the preserved remnants include the Chapel of San Mancio, the clock tower, the Arch of San Benito, fragments of the monastery walls, and the mill located on the Cea River. These dispersed elements form the material basis for understanding the original spatial configuration of the complex (figure 1).

In recent decades, the development of technologies applied to heritage, such as photogrammetry, 3D laser scanning, and 3D visualization systems, has opened new avenues for the documentation, analysis, and virtual reconstruction of heritage. These tools enable the generation of precise digital models, integration of historical and archaeological data, and facilitation of preventive conservation strategies and heritage dissemination. The case of the Monastery of Sahagún thus presents an ideal laboratory for applying digital methodologies that contribute to recovering, interpreting, and disseminating a largely vanished heritage of undeniable historical and architectural value.

Recent virtual reconstruction projects of Cluniac complexes, such as Cluny III in France, have demonstrated the potential of these methodologies to restore complex architectural environments, contributing to their heritage and tourism revaluation [LPCR11].

Figure 1: *Remains of the monastery currently preserved.*

3. Theoretical Framework

The reconstruction of lost architectural heritage presents methodological challenges that necessitate an interdisciplinary approach, integrating art history, archaeology, architecture, and information technologies. In this context, tools such as digital photogrammetry, 3D laser scanning, and 3D modeling have proven effective not only in documenting existing heritage but also in formulating reconstructive hypotheses for partially destroyed monumental ensembles.

From a theoretical standpoint, the concept of "virtual reconstruction" is grounded in the idea of scientific restitution, generating digital models based on documentary sources, historical plans, material remains, and typological analogies. This approach aligns with the principles established in the London Charter [Den09] and the Seville Principles [IFV11], contributing not only to academic research but also to heritage management, intervention planning, and cultural dissemination.

4. State of the Art

The Royal Monastery of San Benito in Sahagún has been the subject of various studies from historical, artistic, and archaeological perspectives. Research by Herráez Ortega [Her00] and Pérez Gil [PG00, PG10a, PG10b] has documented the architectural development of the complex, focusing on the Romanesque and Baroque periods.

The scarcity of preserved remains has, for decades, limited the possibility of a comprehensive architectural reconstruction. The most precise description of the monastery's configuration was provided by the Benedictine monk and historian Romualdo Escalona [Esc82] in the latter half of the 18th century, by which time the monastery had already undergone numerous modifications from its original Romanesque layout (figure 2).

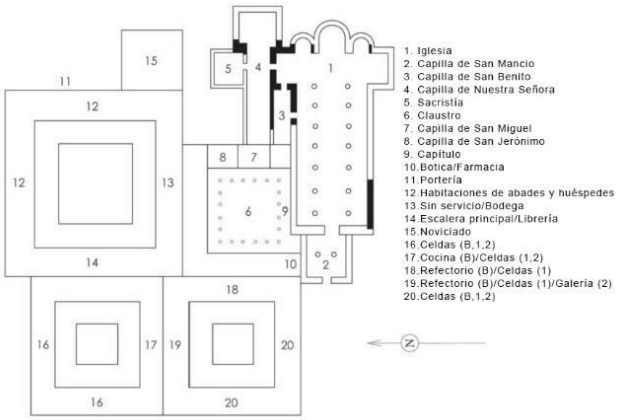


Figure 2: *Approximation of the monastery's layout in the 18th century based on the descriptions by Escalona [Esc82], as interpreted by Pérez Gil [PG10a, p. 114].*

In recent years, various projects have begun to apply digital technologies to the study of the monastery, highlighting the use of three-dimensional scanning for recording the interior of the Baroque church. Parallel cases of virtual reconstruction in Spain, such as the Monastery of Moreruela (Zamora) [IPC66-75], have undergone advanced geometric documentation processes since 2015, demonstrating the viability of these methodologies applied to lost heritage.

5. Objectives

This work proposes the application of advanced digital methodologies to document, analyze, and hypothetically reconstruct the Royal Monastery of San Benito de Sahagún, approaching it from an architectural and historical perspective. The specific objectives are:

1. To analyze the architectural evolution of the monastic complex, based on documentary sources, historical plans, and preserved material remains.
2. To evaluate the potential of digital technologies—particularly digital photogrammetry, 3D laser scanning, and 3D modeling—as tools for the virtual restitution of lost architectural heritage.
3. To develop a rigorous and substantiated digital model of the monastery, enabling an understanding of its spatial configuration, historical evolution, and functional relationships.
4. To contribute to the heritage valorization of the complex through scientifically grounded digital dissemination proposals, aimed at research, education, and cultural and rural tourism.

6. Methodology

The research is structured through an interdisciplinary approach that combines historical-architectural analysis techniques with digital documentation and modeling technologies applied to heritage. The methodology employed comprises three phases:

6.1. Geometric Recording of the Current State

Using combined techniques of photogrammetry and 3D laser scanning, a precise point cloud of the existing remains of the monastery was generated, with a detail resolution of 6 mm at 10 meters.

The choice of equipment and the planning of the data acquisition phase were based on international standards in architectural photogrammetry, particularly those proposed by the CIPA Heritage Documentation committee [WO94; CIP17].

For terrestrial photogrammetry, a systematic collection of photographs was carried out using a Nikon D700, equipped with a full-frame sensor and a 24 mm fixed lens. This configuration enabled the capture of high-resolution images with a ground sample distance (GSD) below 1 mm, ensuring complete coverage of all preserved elements with sufficient overlap to guarantee optimal photogrammetric processing. This setup ensured metric precision in the range of 1–3 mm after bundle adjustment, in accordance with photogrammetric best practices for architectural documentation [WO94]. The photographic acquisition followed a convergent image strategy with over 80% overlap, adapted to the geometry and accessibility of the preserved structures.

Figure 3: *Data acquisition for aerial photogrammetry using a DJI Inspire 2 drone.*

Aerial photogrammetry was executed through several planned flights with a DJI Inspire 2 aircraft equipped with a Zenmuse X7 camera featuring a Super 35 mm sensor and a resolution of 24 MP. Automated flight missions combining nadir and oblique grids achieved GSD values below 2 cm/pixel at 60 m altitude (figure 3). To enhance global accuracy, ground control points (GCPs) were marked with circular targets and measured with a total station. This configuration allowed for the reduction of absolute errors in the final aerial model to below 2.5 cm, in line with international standards for architectural UAV photogrammetry [CIP17].

The acquisition included the following flights:

1. A single-grid nadir flight with the camera perpendicular to the ground at 60 meters altitude.
2. A double-grid oblique flight with the camera tilted 30° relative to the ground (figure 4).
3. Three manual flights for specific details of existing structures.

Laser scanning was performed with complementary equipment:

1. A Trimble X7 time-of-flight scanner, used for exterior documentation, offering a distance accuracy of 2 mm at 10 m and a capture speed of up to 500,000 points/second (figure 5).
2. A Faro Focus 3D scanner, used for the interior of the clock tower and the Chapel of San Mancio, capable of achieving 1 mm precision at short range and offering high angular resolution.

Registration errors between scan stations remained below 4 mm. The datasets obtained from both scanners, characterized by different point densities and scanning geometries, were co-registered and integrated using *Metashape software*. This process resulted in a geometrically consistent, textured 3D model with submillimeter local precision, which served as the reference base for the subsequent virtual reconstruction (figure 6).

6.2. 3D Modeling and Data Integration

In this phase, the data obtained through digital capture techniques were integrated into a specialized three-dimensional environment,

also incorporating reconstructive hypotheses based on historical documentation.

Blender software was used as the main modeling tool, initially importing the models generated through photogrammetry and laser scanning that served as precise geometric references. Based on this, simplified volumetric models representing the lost buildings of the monastery under study were developed.

The modeling of reconstructive hypotheses was carried out by creating simple solids, grounded in the critical analysis of available historical documentation—including old plans, textual descriptions, and archaeological studies. This process followed a methodological approach involving:

Importing point clouds and 3D meshes obtained in the previous phase.

3. Spatial calibration and scaling of the model according to control points.
4. Volumetric modeling of lost architectural elements based on:
5. Analysis of historical plans.
6. Textual documentation (descriptions by Escalona, [Esc82]).
7. Analogies with contemporary Cluniac monasteries.
8. Available archaeological evidence.

A visual differentiation system was implemented between preserved elements (represented with photorealistic texture) and reconstructed ones (visualized with a light neutral color), allowing a clear distinction between existing and hypothetical components.

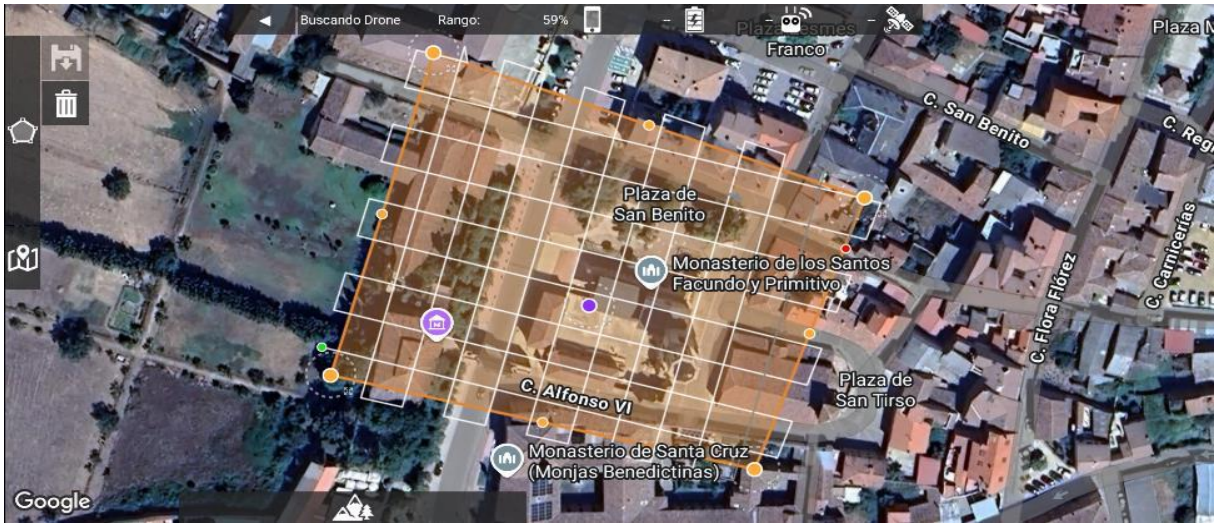


Figure 4: *Flight plan for a double-grid automated mission to capture oblique photographs of the monastery area.*

Figure 5: *(Left) Trimble X7 laser scanner used for digitizing the exterior spaces of the monastery. (Right) Resulting point cloud after aligning all exterior scans.*

6.3. Digital Dissemination Proposal

Based on the developed 3D model, visualizations and virtual tours were designed using advanced spatial representation technologies, catering to different audiences and usage contexts:

The tours were designed in two complementary modalities:

1. 3DoF (Three Degrees of Freedom): allows exploration of digital environments through rotations around the three spatial axes (pitch, yaw, roll), ensuring an immersive experience accessible from common devices.
2. 6DoF (Six Degrees of Freedom): offers complex interaction with linear displacements (surge, sway, heave), enabling free navigation within the virtual space for more immersive experiences (figure 7).

Figure 6: *3D model of the current state of the monastery remains. This model results from merging terrestrial and aerial photogrammetry with laser scan data.*

Figure 7: *6DoF immersive experience of the photogrammetric model of the monastery using a VR viewer.*

These contents were adapted to various visualization devices:

1. Computers and mobile devices (web visualizations).
2. Dedicated virtual reality systems (HMD).
3. Museum installations (projections and interactive screens). c

7. Results and Discussion

The implemented methodological process has enabled the generation of a complete digital model of the Royal Monastery of San Benito de Sahagún, integrating existing elements documented with high precision and hypothetical reconstructions grounded in historical sources.

7.1. Quality and Precision of Digital Recording

The integration of photogrammetric and laser scanning techniques allowed the generation of a reference model with deviations of less than 8 mm compared to control measurements performed with a total station. The highest level of accuracy was achieved in the Chapel of San Mancio, with an average deviation of 3.2 mm, while in geometrically complex elements such as the Arch of San Benito, maximum deviations of 7.6 mm were recorded in areas with limited visibility or reduced access.

The photorealistic texturing of the model, with local resolutions exceeding 3 pixels per millimeter in critical zones, provides not only metric reliability but also high-fidelity material information of great value for constructive analysis and for understanding the historical building techniques employed throughout the monastery.

7.2. Volumetric Reconstruction and Hypotheses

The reconstructive model proposes a complete volumetric representation of the monastic complex, clearly distinguishing three main construction phases:

1. Initial Romanesque configuration (11th–12th centuries).
2. Gothic expansions (14th–15th centuries).
3. Baroque reforms (17th–18th centuries).

The reconstructive hypotheses have been developed with different levels of certainty, categorized according to the reliability of the sources (figure 8):

1. Level A: Elements with direct material evidence (15% of the complex).
2. Level B: Elements documented in historical plans (35%).
3. Level C: Elements inferred by typological analogy (50%).

This categorization allows a critical reading of the model, facilitating its use as a research tool and not merely as a visualization product.

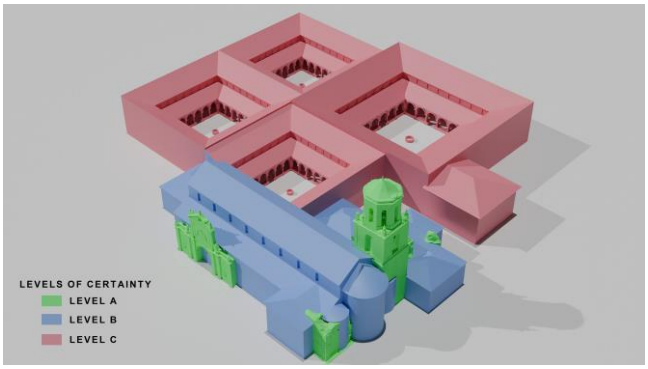


Figure 8: *Reconstructive hypotheses classified by level of certainty: Level A (15%) based on direct material evidence; Level B (35%) from historical documentation; and Level C (50%) inferred through typological analogy.*

7.3. Potential Applications

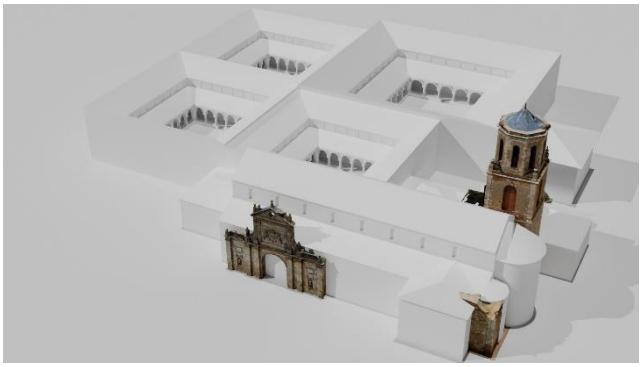
The developed digital model presents numerous application possibilities in various fields:

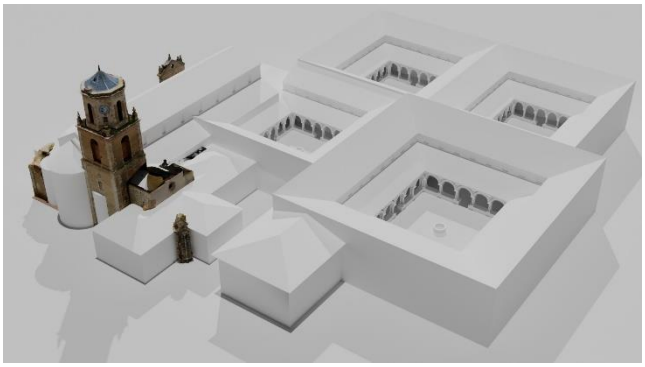
4. Historical-architectural research: The model can be used to test hypotheses about the constructive evolution of the complex and its spatial relationships.
5. Preventive conservation: The precise recording of the remaining elements provides a fundamental documentary basis in case of future deterioration.
6. Heritage dissemination: The digital model can support the development of:
7. Installations in local interpretation centers
8. Web platforms accessible for remote consultation
9. Mobile applications for on-site visits with augmented reality
10. Education: The model can serve as the foundation for the development of specific didactic materials at different educational levels, facilitating understanding of the historical and constructive value of the monastery.

8. Conclusions

The application of digital technologies to the study of the Royal Monastery of San Benito of Sahagún has proven to be an effective tool to address the challenges posed by the analysis of lost architectural heritage. Through the integration of documentary sources, precise geometric recordings, and 3D modeling, it has been possible to reconstruct a coherent and substantiated image of the monastic complex's volumetry (figures 9 and 10).

The generated model not only offers a visual and spatial approximation of the monastery, but also constitutes a knowledge platform that integrates historical, constructive, and archaeological information. This integrative capacity of the 3D environment proves especially valuable in contexts where the materiality of heritage has been severely compromised.





Figures 9 and 10: *3D model with the volumetric hypothesis of the original monastery.*

However, the work presents certain limitations that must be acknowledged:

1. The reconstruction of some interior spaces is based on indirect evidence.
2. The complete evolutionary sequence requires more extensive archaeological comparison.

Ultimately, the experience developed highlights the potential of these methodologies not only for preventive conservation, intervention planning, and heritage dissemination, but also as a foundation for future academic research and possible strategies for the active conservation of lost heritage. The use of digital media facilitates the transfer of scientific knowledge to non-specialized audiences, thereby expanding the social and educational impact of the project.

References

[CDM23] Centre des Monuments Nationaux. *Virtual Reconstruction of the Abbey Church of the Former Cluny Abbey, known as Cluny III*. 2023. https://www.cluny-abbaye.fr/en/discover/virtual-reconstruction-of-the-abbey-church-of-the-former-cluny-abbey-known-as-cluny-iii

[CIP17] CIPA Heritage Documentation. *Principles and Guidelines*. 2017. https://www.cipaheritagedocumentation.org

[Den09] Denard, H. *The London Charter for the Computer-based Visualisation of Cultural Heritage*. Draft 2.1, 2009. http://www.londoncharter.org

[Esc82] Escalona, R. *Historia del Real Monasterio de Sahagún*. Madrid: Imprenta de D. Joachín Ibarra, 1782. https://archive.org/details/bub_gb_NekosAxkADQC

[Her00] Herráez Ortega, M.ª V. (Coord.) *El Patrimonio artístico de San Benito de Sahagún: esplendor y decadencia de un monasterio leonés*. León: Universidad de León, 2000. ISBN: 978-84-7719-781-2. https://publicaciones.unileon.es/product/el-patrimonio-artistico-de-san-benito-de-sahagun-esplendor-y-decadencia-de-un-monasterio-leones

[HCV06] Herráez Ortega, M.ª V., Cosmen Alonso, M. C., Valdés Fernández, M. *Alfonso VI y el monasterio de Sahagún. Nuevos testimonios sobre la construcción del templo monástico*. In: De Arte, Revista de Historia del Arte, 5 (2006), 29–41. https://doi.org/10.18002/da.v0i5.1544

[IFV11] López-Menchero Bendicho, V. M., Grande, A. *The Seville Principles: International Principles of Virtual Archaeology*. International Forum of Virtual Archaeology, 2011. Universidad de León. https://www.vi-mm.eu/wp-content/uploads/2016/10/The-Seville-Principles.pdf

[INP19] Inception Project. *Inclusive Cultural Heritage in Europe through 3D Semantic Modelling*. 2019. https://www.inception-project.eu/en

[IPC66-75] Instituto del Patrimonio Cultural de España (IPCE). *Proyectos de restauración de las ruinas del Monasterio de Santa María de Moreruela de Tábara (Zamora) (1966–1975)*. Madrid: Ministerio de Cultura y Deporte. https://catalogos.cultura.gob.es/opac

[PDC02] Pérez de Castro, R. *Un dibujo de Felipe Berrojo para la portada de San Benito de Sahagún*. In: De Arte, Revista de Historia del Arte, 1 (2002), 75-80. Universidad de León. https://doi.org/10.18002/da.v0i1.1620

[PG00] Pérez Gil, J. *El monasterio románico de los Santos Facundo y Primitivo de Sahagún*. In: Congreso Internacional sobre Restauración del Ladrillo, Sahagún, León 1999. Valladolid: Instituto Español de Arquitectura de la Universidad de Valladolid, 2000, pp. 237–245. https://www.academia.edu/9841003

[PG10a] Pérez Gil, J. *El sueño de Gunzo. Sahagún, El Cluny hispano*. Valladolid: Junta de Castilla y León, 2010.

[PG10b] Pérez Gil, J. *La desamortización de Mendizábal y sus consecuencias en el patrimonio monumental leonés*. León: Diputación de León, 2010.

[REG09] Remondino, F., El-Hakim, S., Girardi, S., Rizzi, A., Benedetti, S., Gonzo, L. *3D Virtual Reconstruction and Visualization of Complex Architectures* – The "3D-ARCH" Project. In: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVIII-5/W1, 2009, pp. 1–6. https://www.isprs.org/proceedings/xxxviii/5-w1/pdf/remondino_etal.pdf

[Sen11] Senra, J. L. *Las grandes instituciones cluniacenses hispanas bajo el reinado de Alfonso VI*. Anales de Historia del Arte, Vol. Extra 2 (2011), pp. 335–366. ISSN: 0214-6452. https://revistas.ucm.es/index.php/ANHA/issue/view/2171

[WO94] Waldhäusl, P., Ogleby, C. *3x3 Rules for Simple Photogrammetric Documentation of Architecture*. ISPRS–CIPA, 1994. https://www.cipaheritagedocumentation.org/wp-content/uploads/2017/02/Waldh%C3%A4usl-Ogleby-3x3-rules-for-simple-photogrammetric-documentation-of-architecture.pdf