

3D Digital Modelling of a Historic City: Methodology of Reconstructing an Image of a City Based on the Case Study of the City of Poznań

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Abstract:

Poznań is a relatively unique case of a city where the central area was significantly recomposed during the past two centuries. Its current shape has lost nearly all of its original, historically formed character. Such far-reaching changes have blurred the image of Poznań's past and its specific landscape. The effect of such a development process of the urban space is incomplete knowledge of the city's historic appearance. Taking into account the above premises, the authors developed a digital twin of the city in the late 18th century, which recreates its historic image. The topic of digital twins of cities is often discussed, however the reconstruction of a digital historic city is quite rare. The main difficulty in this respect is the lack of a clear methodology of working on a reconstruction model, as well gaps in obtaining detailed historic data and lack of access to source materials. The paper discusses the methodology of constructing a digital twin of the historic city of Poznań. The authors present their original method for recreating a specific spatial layout based on analyses of hydrological and natural environments. The key element is the analysis of available sources, the choice and examination of which is presented in the paper.

1. Introduction

The subject of this paper is the process of creating and developing a virtual 3D reconstruction model of the historic city of Poznań. The work is the outcome of long-term research initiated through an analysis of available historical source data, as well as an analysis of the existing layout of the city in situ, including its natural features.

Situated in western Poland, Poznań is one of the largest Polish cities and the capital of Wielkopolska, one of Poland's historic regions. The beginnings of the city are linked to the establishment of the first Polish bishopric and the construction of a fortified settlement with a ducal palatium and an early Romanesque cathedral. It was here that the early stages of the city's subsequent spatial layout emerged.

The present-day urban layouts of many cities across the world are the result of many centuries of accumulation. Subsequent changes transformed the existing municipal systems, turning them into complex structures. It is extremely rare for an average user to recreate and understand changes made in the past. To this day, conservation professionals are not always able to unambiguously assess neither the history nor the material culture of a specific place or region, experiencing a lack of knowledge in this respect. Of great assistance in this process is the recreation of historic cities in the form of digital models.

Today, an often-discussed topic is the construction of digital twin cities. Digital modelling of urban layouts has already been the subject of research, albeit it mainly concerned existing cities (Avena et al. 2021; Ferré-Bigorra et al. 2022; Guzzetti et al. 2023; Lorenzini 2009; Tang et al. 2002). The problem of reconstructing historic cities is addressed less frequently, the main difficulty being the lack of a consistent methodology for working with reconstruction models, as well as gaps related to obtaining detailed historical data and lack of access to source materials.

2. Historical Framework

Poznań is a large urban centre in the western part of Poland. It is a rather unique example of a city where the centre underwent considerable recomposition over the past two hundred years. The main cause of this were the Partitions of Poland and the incorporation of Poznań into the Kingdom of Prussia in 1793. The city's present shape has almost completely lost its original, historically formed character. This happened not only within its anthropogenic sphere but, what is equally important, also its natural areas. Such far-reaching changes blurred the image of Poznań's past and its characteristic landscape. This process of urban development contributed to an incomplete knowledge of its former shape.

In view of the above, the authors developed a digital twin of the city, recreating its historical landscape. This required the creation of a new method for reinventing a given spatial layout and natural environment and transferring it onto the city's digital model.



Figure 1. Historic view of the City of Poznań from Braun and Hogenberg's *Civitates Orbis Terrarum*, Köln 1618

The first royal seat in Poznań was situated on the east bank of the Warta River on the island of Ostrów Tumski. The first fortified settlement was established at the turn of the ninth and tenth century, and by the mid tenth century it began expanding to include a two-part stronghold. The relics of the ducal palatium of the early Piast dynasty were discovered during

archaeological excavations near the existing church of the Blessed Virgin Mary. The reign of the first Piast ruler Mieszko I was a time of the small stronghold's intensive growth, leading to its significant enlargement.

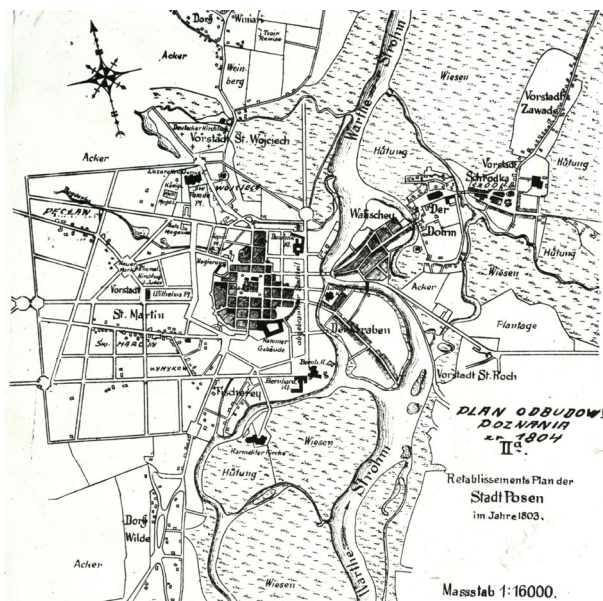


Figure 2. Plan for the expansion of Poznań of 1803 (*Relaissements Plan der Stadt Posen*), source: Cyryl repository

In 1253, the city was relocated to the left bank of the Warta River and was granted an urban charter. This initiated a new spatial arrangement, which was a uniform urban composition based on the universal square plan. What was unique in the planning of Poznań was that its commercial part was offset with the blocks of the Weighing House and the City Hall. Magdeburg rights, upon which the city was founded, as well as the spatial layout of the market square based on a long-known archetype, determined a clear organisation and orientation of space. The market square and the checkered system of streets, as well as the proportions and divisions of space, formed a perfect illustration of the eternal order of the world contained within a pragmatic town planning programme. Simultaneously, the right-bank section of the city concentrated around a site of religious worship with a Gothic cathedral. The programme is legible to this day and undoubtedly constitutes the core of the city, especially since recent archaeological excavations make it possible to observe the remains of important contemporary buildings that had been forgotten over the course of history.

Surrounded by medieval walls, the city survived unchanged until the late 18th century. Of course, many new buildings were erected, but these filled the city's previously planned composition. Numerous *jurydyki* (settlements situated directly outside the royal city) developed into suburban structures. It can be said that the development of Poznań over the years was reminiscent of a spatial palimpsest (Biskupski 2013) (Marciniak 2020; 2024).

Why did the authors of this paper choose to work on the image of the city from the 18th century? To answer this, one should note that Poznań owes its current layout to a Prussian town planning campaign conducted between 1793 and 1806, aiming to make it similar to other cities in the Kingdom of Prussia (Ostrowska-Kęłowska 2009). The expansion of the medieval city area was a project intended to build a new western district. A city plan from 1793 shows Poznań inside much earlier medieval boundaries, with numerous settlements situated

outside the city walls. The Prussian urban development campaign launched not only the construction of a new district, but also the transformation of the entire city. The transformations continued even after Poland regained independence in 1918. Subsequently, the intensive urban expansion of the past two centuries forever changed the historic city layout that dated back to the Middle Ages.

3. Methodology

One of the major problems in historical reconstruction is the varying quality and completeness of source data. It is therefore crucial to critically analyse the available sources. This is key to the proper identification of historic spatial conditions. Crucial factors in the case of Poznań included an analysis of the hypsometric arrangement and hydrologic conditions, as well as systems known from many source materials, mainly maps. In many cases, it was possible to accurately reconstruct some areas, based on well documented sources, whilst other cases were based on scarce, unclear or fragmentary data and are of an approximate nature. Hence the level of representation varies from LOD 2 to LOD 4.



Figure 3. Spatial analysis of the Chwaliszewo settlement: a) section of Rosler's plan b) reconstruction, source: authors

In the case of individual buildings, the data obtained also varied in terms of detail (from LOD 2 to LOD 3), ranging from rather general data to detailed information found in descriptions, drawings and even photographs (e.g. the City Hall and the Cathedral). In this case, the level of accuracy grew to LOD 4. The authors assumed they would use verified data, limiting the level of speculation only to exceptional cases. The key materials included historic city maps, cadastral maps, descriptive texts of a source material nature and the available iconography, including historic drawings and photographs. The verified credibility of these sources made a considerable impact on the quality of the digital model.

It should also be explained that the final digital reconstruction covered several consecutive historical periods and phases of the city's development since its foundation in 1253. At the same time, the development of the reconstruction was a reverse process, working back from the present day to the late 18th century. The final outcome is the shape of the urban and peri-urban space in the latter period. An attempt to illustrate the specific development phases up to the 18th century is possible, however it was beyond the scope of this project.

It is obvious that there were gaps in the historic records, and sources were often contradictory or ambiguous. In such cases, interpretation decisions were based primarily on the available maps and iconographic sources. The authors assumed that in the absence of definitive evidence, the original spatial forms were most fully reflected by visual representations.

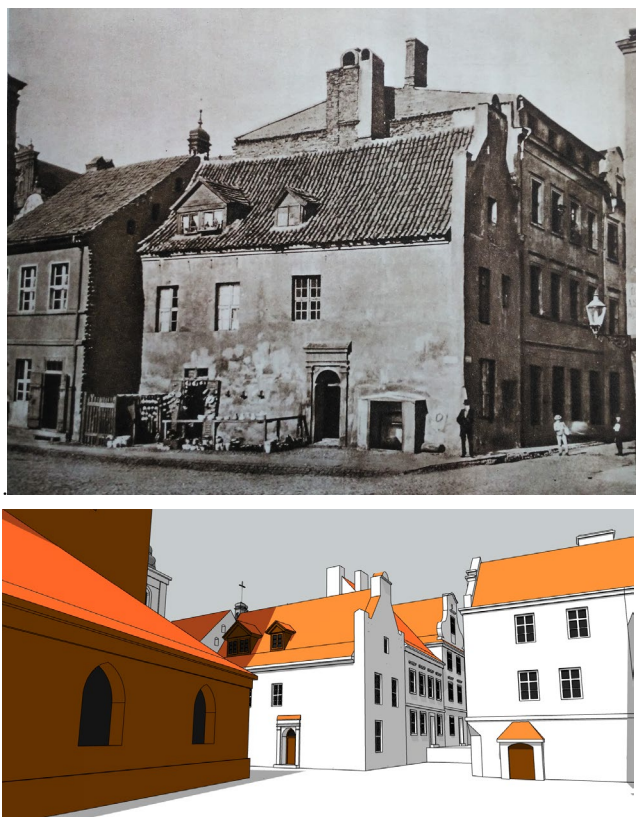


Figure 4. Reconstruction of a section of the city: a) archival photograph b) model, source: authors

The historical data comes from available archives, libraries, iconographic records from the early 17th century and digital repositories, as well as the System of Spatial Information of the City of Poznań (System Informacji Przestrzennej Miasta Poznania). Earlier, other than contemporary sources, historic information had not been georeferenced. In this respect, various types of source notes, descriptions, drawings and city maps proved very useful, in particular historic views of Poznań and old photographs (Warkoczewska 1960; 1983). It is impossible to list all of these, however one should mention a view of Poznań from 1618 presented by George Braun and Franz Hogenberg in volume VI of their *Civitates Orbis Terrarum* atlas (Köln 1618) and F. B. Werner's panorama from 1740, as well as the following maps: plan of the City of Poznań from 1793 (*Die Stadt Posen im Jahre 1793*) and plan for the expansion of Poznań from 1803-1804 (*Retablissements Plan der Stadt Posen*).

The key elements of the adopted method included:

- a historical comparative analysis of numerous research studies and iconographic materials, including plans and maps of Poznań created between the 18th century and the present; in addition to iconographic sources, descriptions of the space of both individual buildings and larger sections of the city played an important part in the recreation of buildings; this was a type of hermeneutic approach to understanding historical spaces;
- the authors' method for analysing transformations, consisting of a detailed assessment of the available maps, views and source documents; the analysis also covered specific features of the landscape and the terrain (hypsometry); based on this, it was possible to determine the layout and structure of watercourses and the historic terrain, as well as historic ownership structures;
- the final part of the project was the recreation of the elements that made up the landscape of historic Poznań and the development of a virtual, spatial model of the city in the 18th century; the model includes both the terrain and the historic shapes of buildings that existed in the past; the digital 3D image of the city is a summary of the classical archival research and, simultaneously, a spatial visualisation of the applied analytical method.

The subject of the project was a method for recreating a digital model of the city based on a detailed analysis of historical data. The analysis made it possible to recreate (model) the former shape of Poznań's natural surroundings and its historic urban system. Such a model can be useful in spatial decision making, conservation policies and educational processes.

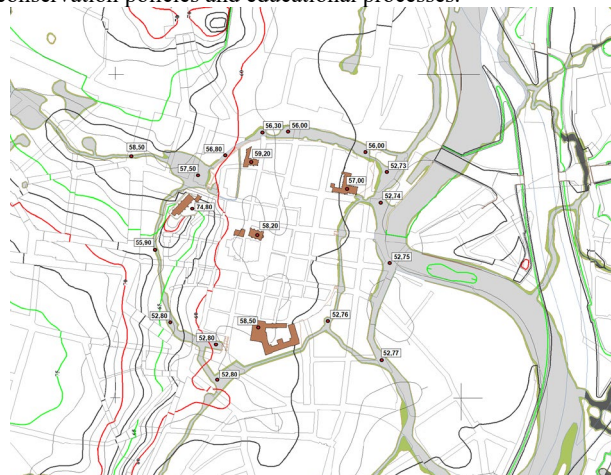


Figure 5. Poznań: process of recreating the historic hydrological and elevation systems, source: authors

The aim of this presentation is to demonstrate the authors' method for digitally recreating the model of a historical city and its digital reconstruction. This involves the reconstruction of the city's historic layout based on analysing watercourses and historical sources. Poznań and its spatial layout and natural conditions in the late 18th century will serve as an example of applying the method in practice. The final effect is a presentation of a virtual 3D image of the city.

4. Description of the Research Project

The subject of the research project was an analysis of spatial changes that took place in the old town area of Poznań over the past two centuries, that is in the 19th and 20th centuries.

The objective was to digitally recreate the spatial landscape of Poznań in the 18th century, for which no consistent iconographic records have survived. The research area covered the present-day city centre of 2161 hectares. The authors analysed the following elements: hydrological system, terrain, plot layout, shape of buildings, use of individual plots and street and road system, as well as high, medium and low vegetation.

In addition to the structure of Poznań (a chartered town) itself, the authors also analysed twenty-eight settlement units that surrounded and contributed to the city's spatial complexity during the pre-Partition period. These included: Garbary, Chwaliszewo, Ostrów Tumski, Ostrówek, Śródka, Komandoria, Zawady, Główna, Święty Roch (Stanisławowo), Piotrowo, Berdychowo, Rataje, Grobla, Gaski, Czapniki, Rybaki, Półwieś, Wilda (Wierzbice), Święty Łazarz, Święty Marcin, Nowe Ogrody, Wenetowo, Kundorf (Peclaw), Jeżyce, Święty Wojciech, Winiary, Bonin and Szeląg. The listed names correspond to present-day districts and are a good point of reference for analysing Poznań's spatial structure.

The point of departure for the particular analyses was the modern ownership structure of Poznań and its terrain in hypsometric form. This included specific elements of the landscape and hydrological environment, which allowed to recreate a historic model of the city (the particular stages and description of sources is provided in Table 1).

1. Based on the modern ownership structure, the authors recreated and determined the shape and extent of most of the watercourses that formed the wide-ranging hydrological network in Poznań in the eighteenth century.
2. Based on the identified watercourse area and the modern terrain, the authors determined all the elevation coordinates of the historic hydrological system contributing to the landscape of pre-Partition Poznań.
3. Based on the determined hydrological system and its elevation, as well as an in-depth analysis of transformations that took place in given areas over the past 200 years, the authors recreated the historic terrain in the analysed area.
4. Based on the modern ownership structure, the authors determined the lines and properties that are preserved in their form from the 18th century. Based on this, they recreated the historic plots that formed the historic settlement structures of the conurbation.
5. Based on the iconography of historic drawings and photographs, the authors analysed over ten thousand buildings in terms of form, scale and detail contributing to the complexity of the chartered town and its surrounding structures.
6. Based on numerous plans and maps from the 18th and 19th centuries, the authors determined the layout of high, medium and low vegetation within the historic plots, as well as within the space surrounding the individual plots.
7. Based on numerous plans and maps, the authors recreated the street system that formed a network of the roads that functioned in Poznań during the analysed period.

The final outcome of the project was the recreation of the features that formed the landscape of Poznań prior to the Partitions and the development of a virtual 3D model of the city in the 18th century.



Figure 6. 3D model of the Śródka settlement unit as seen from the west, source: authors

The presented findings are the result of long-term research that included numerous queries in the Poznań City Archive, the National Archive in Poznań, the Adam Mickiewicz University Library and the Raczyński Library. The queries made it possible to analyse a number of plans and maps from the 18th and 19th centuries, as well as an entire iconographic resource of drawings and photographs showing the buildings and landscape of Poznań from the pre-Partition period (Biskupski 2024).

Over the past two centuries, the central area of Poznań was significantly transformed. The changes have affected the entire hydrological system and terrain, as well as the compositional spatial layout and green areas. The changes caused a complete loss of the city's image from the late 18th and early 19th centuries. The authors' carried out the research project to provide a full overview of the urban space and to recreate the spatial layout of the historic city. The resulting model and the subsequent visualisations make it possible to look at the city from a historic perspective and to understand its spatial and landscape features.

5. Results and Discussion

The final part of the presented historical research project was the reconstruction of elements of the spatial landscape in pre-Partition Poznań and the creation of a virtual spatial model of the city in the 18th century. The 3D image of the city summarises an entire research cycle, including standard archival research and source analyses. The visualisation stage of the project is simultaneously its spatial visualisation. The digital 3D model of the city was created using SketchUp PL software. To begin with, the authors built a hypsometric model of the terrain and the system of watercourses around the Warta River and its tributaries, including Bogdanka, Wierzbak, Struga Wildecka, Struga Karmelicka, Noteć, Cybina, Piaśnica and Główna. Next, the authors worked on individual buildings and spatial complexes.

The obtained level of detail in the LOD CityGML city model results from the available historic data sources and assumes a LOD 2 (or LOD 3) level for areas of dense urban context, where due to the lack of specific data on the history of individual buildings the accuracy is average.

Table 1. Types of sources used to recreate the shape of the city in the 18th century. The point of departure for the particular analyses was the modern ownership structure and terrain in hypsometric form. The research included specific features of the hydrological system and the landscape, which, at the same time, constituted subsequent stages leading to the recreation of a historic model of the city in the form of digital reconstruction of buildings.

ELEMENTS OF THE CITY STRUCTURE (RESEARCH STAGES)	SCOPE OF ANALYSIS	ARCHIVAL MATERIALS	DATA AND SOURCE	CITYGML LOD	IFC LOD
form and extent of most watercourses contributing to the wide-ranging hydrological network in Poznań in the 18 th century	modern ownership structure historic maps and city plans of Poznań descriptive forms	System of Spatial Information of the City of Poznań https://sipgeoportal.geopoz.poznan.pl National Archive in Poznań Virtual Museum of the History of Poznań CYRYL https://cyryl.poznan.pl/ Poznań Society for the Advancement of Arts and Sciences Adam Mickiewicz University Library		LOD 2-3	LoD 200 LoD 300
determination of all the elevation coordinates of the historic hydrological system contributing to the landscape of pre-Partition Poznań	identification of the hydrological area modern terrain	System of Spatial Information of the City of Poznań https://sipgeoportal.geopoz.poznan.pl		LOD 2-3	LoD 200 LoD 300
recreating the historic terrain in the analysed area	based on the determined hydrological system and its elevation, an in-depth analysis of transformations performed in given areas over the past 200 years	System of Spatial Information of the City of Poznań https://sipgeoportal.geopoz.poznan.pl		LOD 2-3	LoD 200 LoD 300
recreation of the historic plots that formed the historic settlement structures of the conurbation	ownership structure determination of the lines and properties that preserved their shape from the 18 th century	System of Spatial Information of the City of Poznań https://sipgeoportal.geopoz.poznan.pl National Archive in Poznań Adam Mickiewicz University Library		LOD 2-3	LoD 200 LoD 300
buildings (over ten thousand)	iconography (historic drawings) archival photographs descriptive forms (source texts)	Virtual Museum of the History of Poznań CYRYL https://cyryl.poznan.pl/ National Archive in Poznań Poznań Society for the Advancement of Arts and Sciences Adam Mickiewicz University Library		LOD 2-3-4	LoD 200 LoD 300 LoD 400
layout of high, medium and low vegetation within historic plots and surrounding space	historic maps and plans from the 18 th and 19 th centuries descriptive forms (source texts)	National Archive in Poznań Raczyński Library Virtual Museum of the History of Poznań CYRYL https://cyryl.poznan.pl/ Adam Mickiewicz University Library		LOD 2-3	LoD 200 LoD 300
road system in Poznań in the analysed period	historic city maps and plans	National Archive in Poznań Raczyński Library Adam Mickiewicz University Library Virtual Museum of the History of Poznań CYRYL https://cyryl.poznan.pl/		LOD 2-3	LoD 200 LoD 300



Figure 7. 3D model of the medieval city as seen from the south, source: authors

The buildings of the suburban settlements, villages and *jurydyki* display well-developed bodies and roofs along with their shape and orientation. The vast majority of buildings within the city walls, as well as individual buildings beyond these, were constructed at the LOD 3 level of detail for external architectural models where the accuracy is high. The structure of the buildings is represented in its actual form, as are the roofs and the elements of external details (Avena et al. 2021). The authors supplemented the cubature data with information of historic nature. Further specifications of subgroups were added to the initial CityGML classification, enriching the general specifications. BIM literature refers to the level of geometry (LOG) and level of information (LOI), which are combined into level of development (LOD) (Biljecki et al., 2016). In this context, the presented model of the city of Poznań can be said to display a maximum of LoG300 and LoI400 in BIM, which

escapes accepted consistent classification. The model consists of detailed information obtained on the basis of data concerning the shape of buildings and much more precise information on their history and subsequent transformations.



Figure 8. 3D model of the Ostrów Tumski settlement unit as seen from the southwest, source: authors

A separate issue is the level of accuracy of the terrain. This is the effect of overlapping data from historic maps that do not share a single common design or structure. This extremely tedious work focused on “translating” the available information from historic maps and descriptions into the city’s present-day layout and structure. Hence to ensure an accurate and satisfying outcome of the research project it was so important to use the methodology for analysing the “compatibility of the indirect elements of the landscape, where each section of space recorded in both the 18th and 19th centuries, as well as the 20th century built, confirmed and completed, but also uncovered the comprehensive image of a place of the past. This referred to

both natural and anthropogenic elements. Within this method, every form of record, even the most imperfect, was invaluable, since without it, it would be impossible to recreate a realistic and fuller image from the past not only in heuristic terms, but above all, due to relatively limited social awareness, also from a phenomenological perspective.



Figure 9. 3D model of the city of Poznań as seen from the historic town centre, source: authors.

6. Conclusion

The digital spatial model of the city of Poznań is an example of the extensive possibilities offered by the combination of traditional historic research methods with modern digital technology. Before this, it was difficult to imagine the historic shape of urban spaces and to enjoy the opportunity to see and compare them from different perspectives. Obviously, handmade mock ups also provided interesting possibilities but creating these was a very tedious and costly process, whilst some features, for example the terrain, required digital references and processing in the form of vector drawings. In the discussed case, source information was collected in a traditional way and made a reference to analogue data, however its processing was fully digital.

It may seem that the presented project is yet another three-dimensional reconstruction of a city based on historic source materials. However, the authors believe that their model can be classified as a digital twin. There are plans to integrate some of the data, for example the hydrological conditions, fire hazards and urban logistics. The determined methodological path offers a range of completely new possibilities for creating historic city models. It also makes it possible to recreate urban space for other fields of research.



Figure 10. 3D model of the Old Market Square with the City Hall and visible tower of St Mary Magdalenes church, source: authors.



Figure 11. 3D model of the city of Poznań as seen from the north, source: authors.

The modelled shape of the historic city of Poznań in the late 18th century provides an image of the characteristic elements which have become its permanent feature and determine its spatial layout. These visualisations can be continued, extended, developed and directed towards the future. In other words, they can be used in creative ways. The digital twin of Poznań in the 18th century is not just a static model, but also a dynamic HBIM copy which will ensure a better understanding of historic processes and can be used in the conservation and restoration of historic heritage. It is especially important to model and understand urbanisation processes, as well as green area and hydrological systems, in addition to preserving the most important cultural assets as seen from the present-day perspective. This presents a unique opportunity to work with a digital twin of an eighteenth-century city.



Figure 12. 3D model of Ostrów Tumski and the cathedral as seen from the north, source: authors

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