A relational database for the digitization of fluvial architecture: conceptual scheme and overview of possible applications

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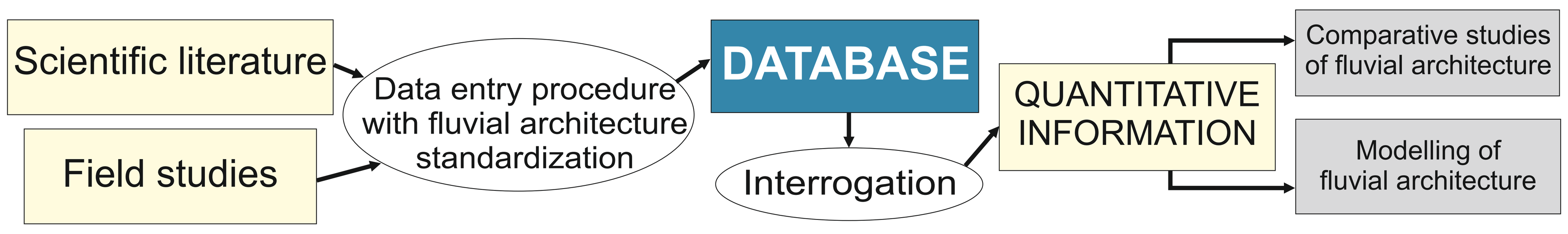
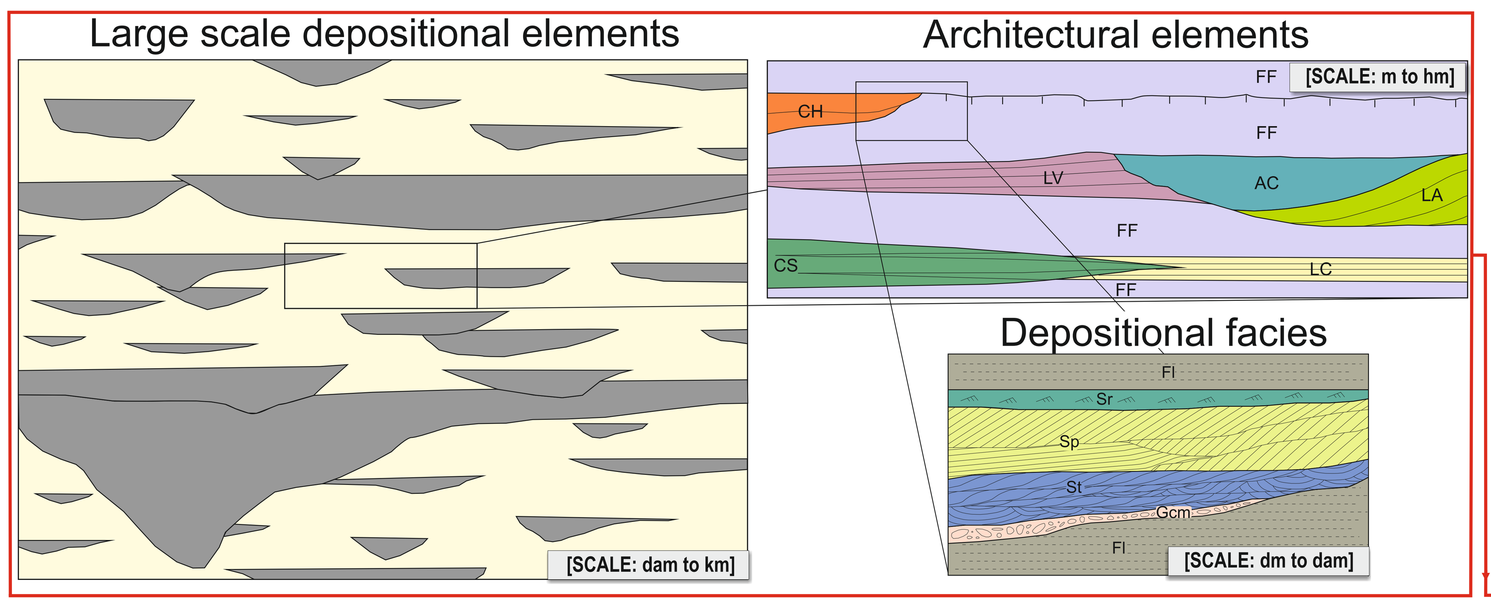
INTRODUCTION

Fluvial architecture is the ensemble of geometry, proportion, internal organization and spatial distribution of genetic bodies within fluvial successions (cf. Allen, 1978). A **relational database** - the **Fluvial Architecture Knowledge Transfer System** (**FAKTS**) - has been devised as a tool for translating numerical and descriptive data and information about fluvial architecture coming from fieldwork and peer-reviewed literature, from both modern rivers and their ancient counterparts in the stratigraphic record. The work herein presented focuses on the latter case, showing the basic concepts about the database scheme and data definition, and some possible outputs and their applications.



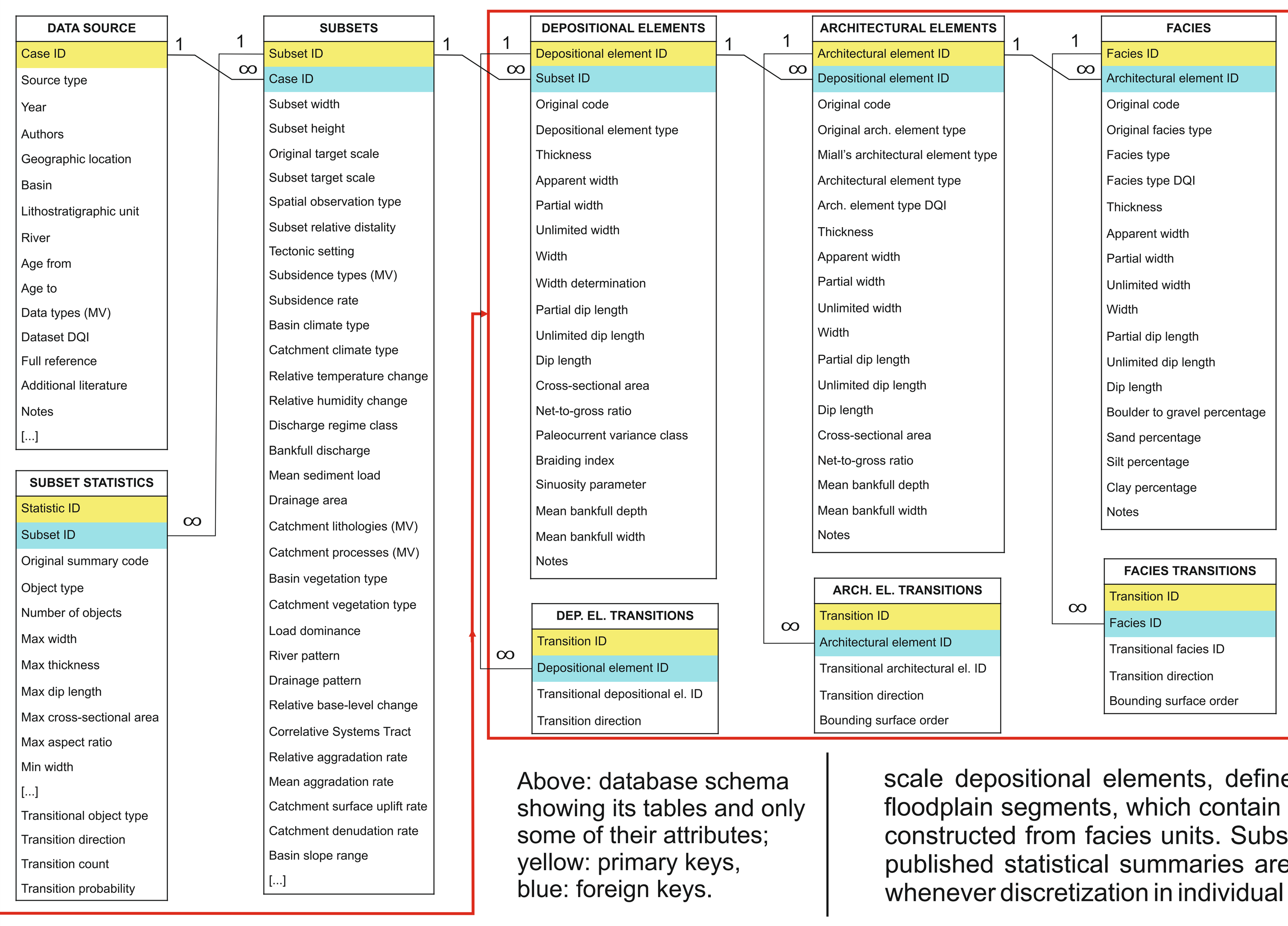
Above: flowchart showing the data acquisition-entry-query-analysis/use workflow described in this poster.



Right: representation of the main scales of observation and types of geological objects translated into the database in the form of tables and entries respectively.

DATABASE SCHEME - the approach

The stratigraphy of preserved ancient successions is translated into the database schema in form of geological objects belonging to different scales of observation, nested in a hierarchical fashion. Each order of objects is assigned a different table and each object within a table is given a unique numerical identifier that is used to keep track of the relationships between the different objects, both at the same scale (transitions) and also across different scales (containment). Each single dataset is split into a series of stratigraphic windows called subsets, that are characterized by homogeneous attributes, such as internal and external controls. Each subset contains large scale depositional elements, defined as channel-complexes and floodplain segments, which contain architectural elements that are constructed from facies units. Subset statistical data coming from published statistical summaries are included in a separate table, whenever discretization in individual objects is not possible.



Above: database schema showing its tables and only some of their attributes; yellow: primary keys, blue: foreign keys.

DATABASE SCHEME - implementation

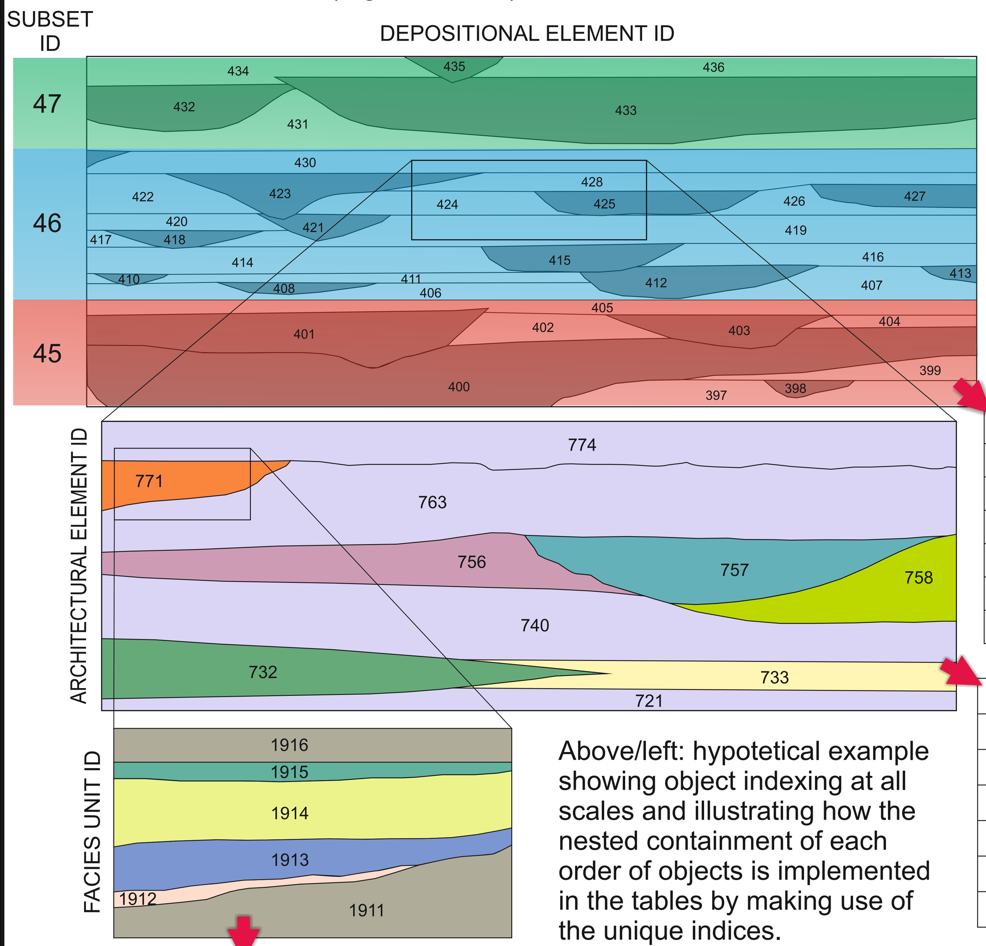
The building blocks of fluvial architecture, belonging to the different scales considered, are recognizable as lithosomes in ancient successions, in both outcrop and subsurface datasets. The original recognition of these entities is essentially the result of 1D/2D/3D data interpretation: the tables associated to these objects contain a combination of interpreted soft data (e.g. object type) and measured hard data (e.g. thickness).

CH	Channel-fill
DA	Downstream accreting barform
LA	Lateral accreting barform
DLA	DA and/or LA barform
SB(CH)	In-channel sandy bedform elem.
SG	Gravity flow body
HO	Scour hollow fill
FF	Overbank fines element
CS	Crevasse splay / lacustrine delta
CR	Crevasse channel
LV	Levee
SF	Sandy sheetflood dom. floodplain
AC	Abandoned channel
LC	Lake
C	Coal body

Left: **ARCHITECTURAL ELEMENT TYPE CLASSES** - modified after Miall (1996) -

Below **FACIES UNIT TYPE CLASSES** - modified after Miall (1996) -

G-	Gravel to boulder, undefined structure	Sr	Ripple X-laminated sand
S-	Sand, undefined structure	Sh	Horizontally bedded sand
F-	Silt to clay, undefined structure	Sl	Low-angle X-bedded sand
Gmm	Matrix supported massive gravel	Ss	Scour-fill sand
Gmg	Matrix supported graded gravel	Sm	Massive sand
Gci	Clast supported inverse graded gravel	Fl	Laminated sand, silt and clay
Gcm	Clast supported massive gravel	Fsm	Laminated or massive silt and clay
Gh	Clast supported crudely bedded gravel	Fm	Massive clay and silt
Gt	Trough X-bedded gravel	Fr	Root bed
Gp	Planar X-bedded gravel	C	Coal
St	Trough X-bedded sand	P	Pedogenic carbonate
Sp	Planar X-bedded sand		



Above/left: hypothetical example showing object indexing at all scales and illustrating how the nested containment of each order of objects is implemented in the tables by making use of the unique indices.

facies_ID	arch_el_ID	facies_type
1911	763	Fl
1912	771	Gcm
1913	771	St
1914	771	Sp
1915	771	Sr
1916	774	Fl

DATA DEFINITION AND CROSS-SCALE RELATIONSHIPS

A set of rules has been established to keep object definition as coherent and objective as possible. Depositional elements are defined on the basis of sound geometrical criteria, rather than on their geological significance. Classification of architectural element and facies unit types broadly follow Miall's (1996) scheme, though original classes used in the source works are also maintained. Every single object is assigned a numerical index that works as its unique identifier; these indices are used to relate the tables (as primary and foreign keys) reproducing the nested containment of each object type within the higher scale parent object (depositional elements within subsets, etc.).

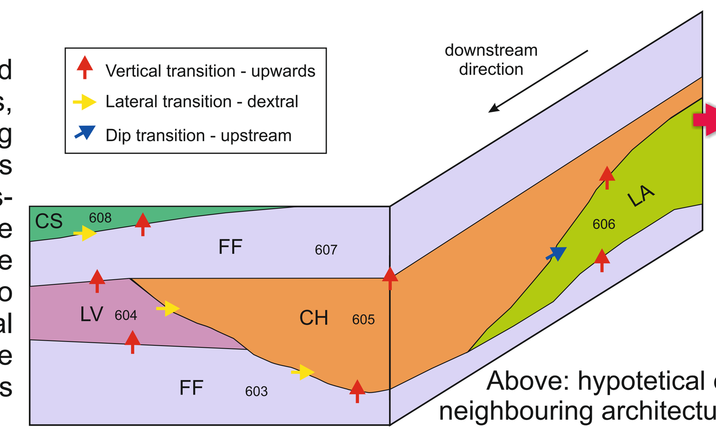
dep_el_ID	subset_ID	dep_el_type
419	46	floodplain
423	46	channel_complex
424	46	floodplain
425	46	channel_complex
428	46	floodplain
430	46	floodplain

arch_el_ID	dep_el_ID	arch_el_type
721	419	FF
732	419	CS
733	419	LC
740	424	FF
756	424	LV
757	425	AC

DIMENSIONAL PARAMETERS The dimensions of each depositional element, architectural element and facies unit can be stored in their tables as representative thicknesses, cross-valley widths and downstream lengths, each classified according to the completeness of the observations into complete, partial and unlimited lengths, since some observations are truncated at one limit of the observation window (partial lengths), whereas some others at both ends (unlimited lengths); their attribution depends also on the type of data available (e.g. well correlation vs borehole correlation). Cross-valley cross sectional areas of the lithosomes can be also stored.

OBJECTS TRANSITIONS

The same numerical indices that are used for representing containment relationships, are also used for object neighbouring relationships, represented within tables containing transitions in the vertical, cross-valley and along-valley directions. The hierarchical order of the bounding surface across which the transition occurs is also specified at the facies and architectural element scales; the bounding surface hierarchy proposed by Miall (1996) has been adopted.

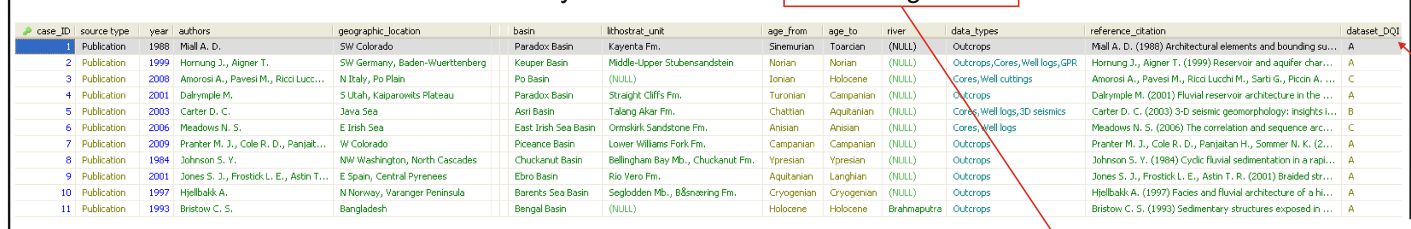


arch_el_ID	trans_el_ID	trans_direction	bound_surf_order
603	604	vertical	4th
603	605	lateral	5th
603	605	vertical	5th
603	606	vertical	5th
604	605	lateral	4th
604	607	vertical	4th
605	606	dip	4th
605	607	vertical	4th
606	605	vertical	4th

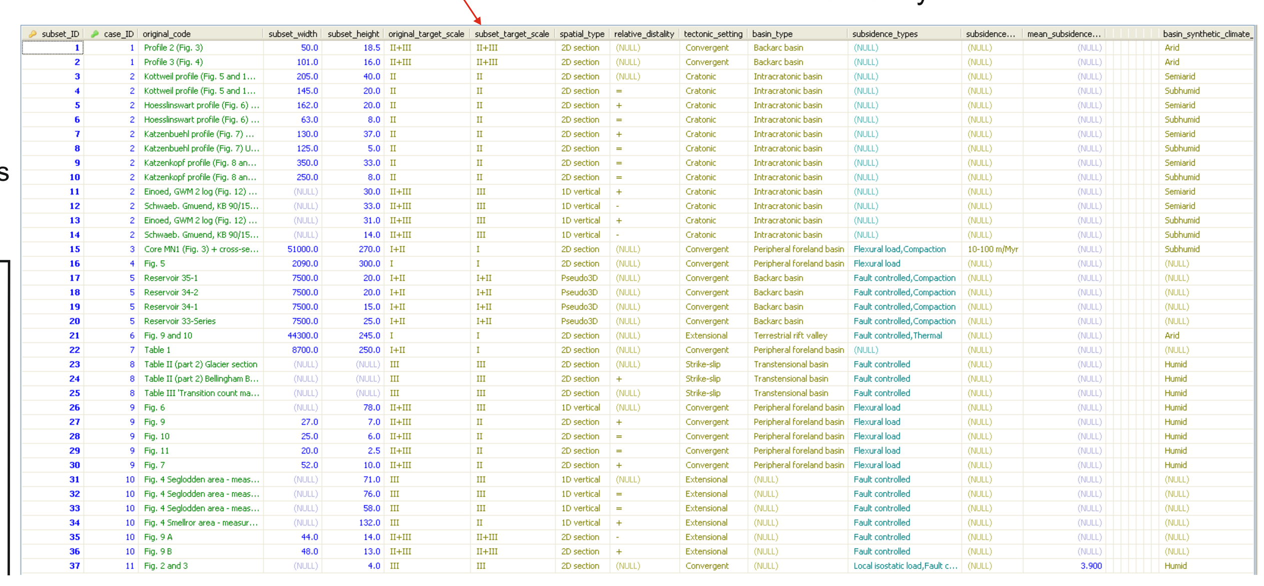
Above: hypothetical example illustrating how transitions between neighbouring architectural elements are stored within the database.

CASE STUDIES CLASSIFICATION

Most of the metadata that refers to the original source of data/information (e.g. type of data acquisition) is stored within the most external table, for each case study. The attributes for each subset comprise some more metadata (e.g. original coding, type of spatial observation...) and all the categorical and numerical variables that are used to define the subsets themselves (e.g. climate type, subsidence rates, river planform pattern, etc.). The amplitude of a subset determines the types of objects that are suitable for its characterization: they are stated as the *subset target scale*.



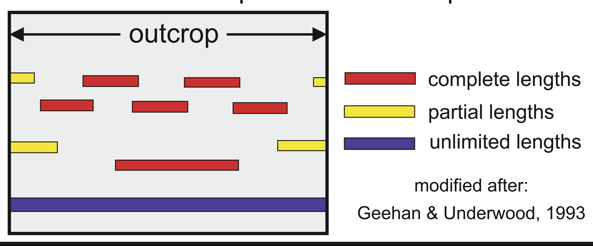
Excerpts from *data_source* (above) and *subsets* (right) tables. This *subsets* table consists of 58 attributes, some of which are meant for ancient or modern cases only; this table is editable and extendable at any time. Some of these attributes are only expressed as relative change (=, -, +) in a given variable between subsets.

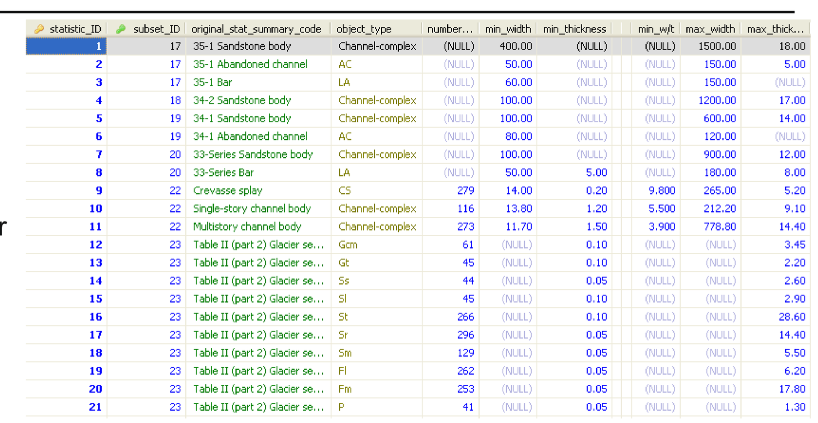


DATA RANKING

A series of data quality indices (*DQI*) have been implemented in the scheme as a threefold rating system to allow the ranking of data quality and reliability, and to filter it accordingly. Although the *dataset DQI* rates the entire case study, other DQI's are used for ranking class domain attribute assignment for each entry.

Below: representation of categories of completeness (Geehan & Underwood, 1993) of observed/sampled dimensional parameter.

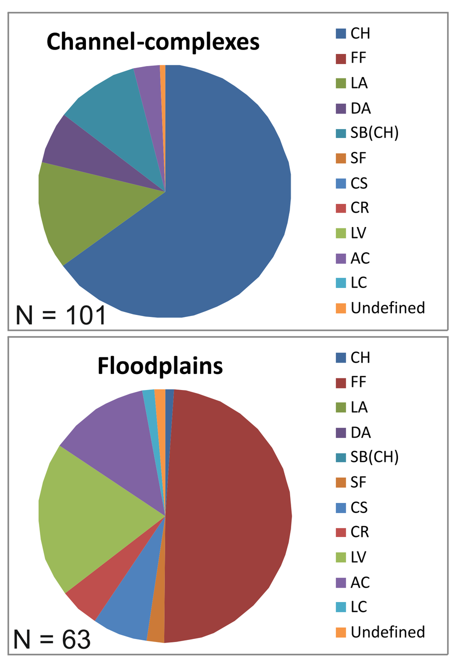




Right: excerpt from the *subset_statistics* table, containing descriptive statistics of dimensional parameters and transition statistics for objects which cannot be individually digitized, as derived from statistical summaries.

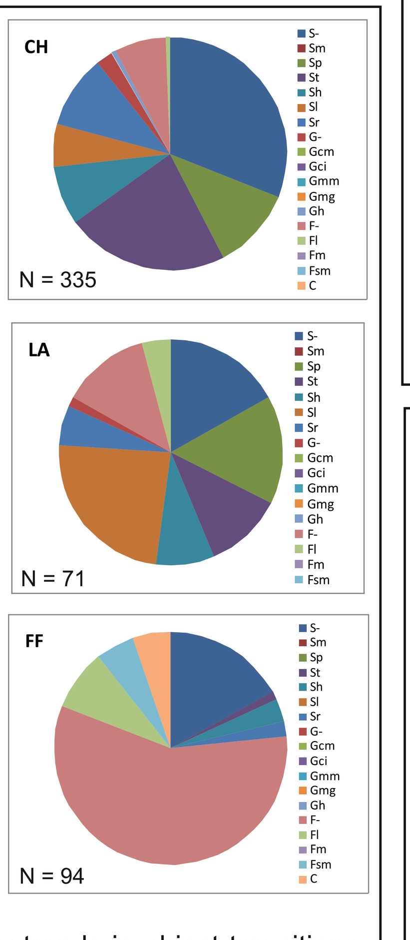
OUTPUT AND APPLICATIONS

The database is presently running on the *MySQL* Database Management System, so it can be simply interrogated through SQL queries, in order to generate quantitative information. **Example output** resulting from database interrogation is introduced here to show the potential of this database as a tool for the quantitative characterization of fluvial architecture. The information that can be derived may prove to be useful for comparing different cases, answering general research questions about the interpretation of fluvial architecture and for guiding its prediction in the subsurface: example applications are briefly presented.

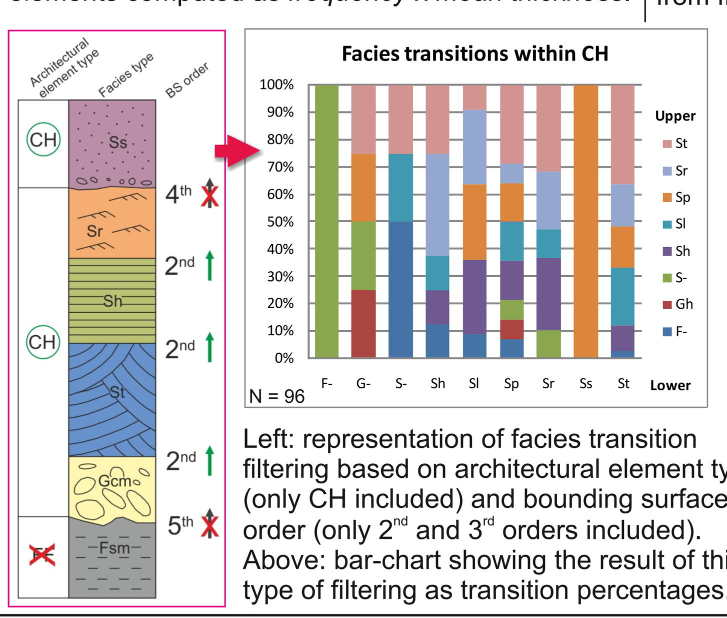


The **internal organization of genetic packages** can be characterized in terms of the objects belonging to lower order scales. First of all, information on their **composition as a relative proportion of their building blocks** can be obtained. For example, the internal composition of channel-complexes or floodplains in terms of architectural elements, and of architectural elements in terms of facies units (as shown in the pie-charts) can be derived by object occurrences only, or by combining occurrences and dimensions in a variety of ways; net:gross ratios can then be easily computed for each object.

Above: proportions of architectural elements in channel-complex and floodplain depositional elements computed as *frequency x mean thickness*.



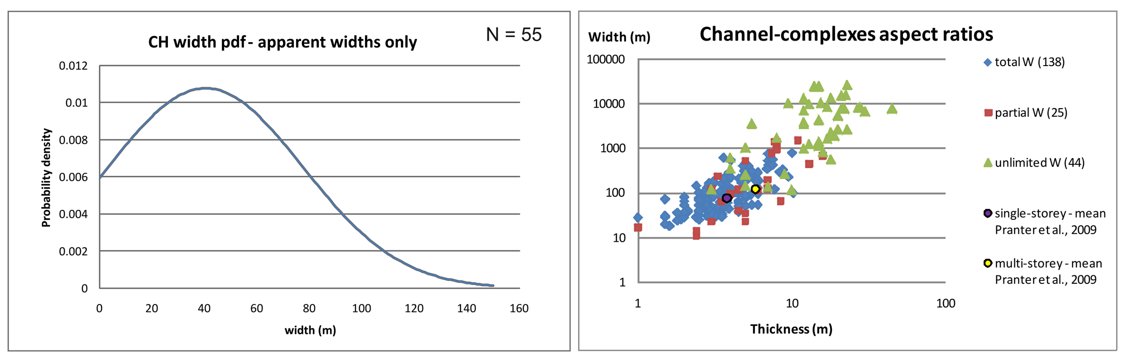
Right: proportions of facies units in CH, LA and FF architectural elements computed from frequencies only.



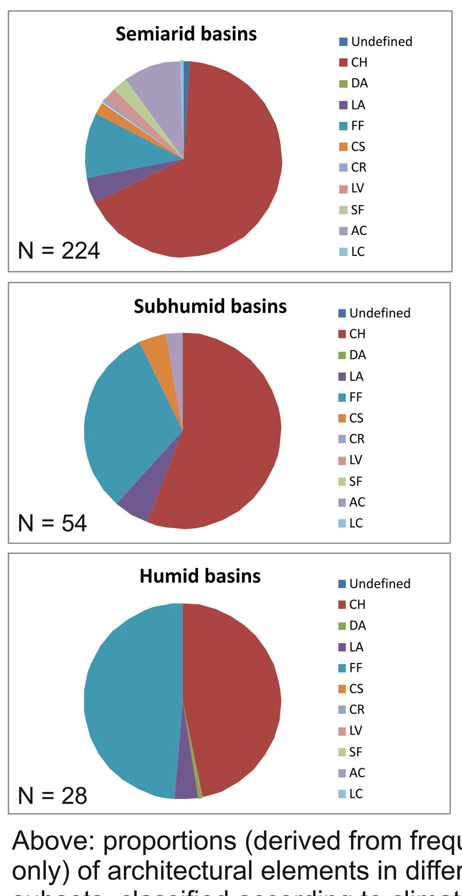
Trends in spatial distributions are described by trends in object transitions. To further characterize genetic bodies, data on transition occurrences can be filtered so that only transitions observed within the type of element investigated and across given bounding surface orders are taken into account. After filtering 2D and 3D datasets with random selections in order to force the transition sampling to be one-dimensional, 1D transition count matrices can be obtained for any direction, and transition probability matrices thereby derived.

Left: representation of facies transition filtering based on architectural element type (only CH included) and bounding surface order (only 2nd and 3rd orders included). Above: bar-chart showing the result of this type of filtering as transition percentages.

The information we can derive about the internal organization of the geological objects can be coupled with information about their **external geometry and dimensions**: we are able to compile elaborations such as probability density functions of dimensions or syntheses of aspect ratios for any object type, choosing whether to include or not underestimated (partial and unlimited) and overestimated (apparent) dimensions.



Above: probability density function of CH architectural elements width constructed using only apparent widths (on the left); scatter-plot of channel-complexes width:thickness aspect ratios classified according to dimension completeness class (on the right).



Above: proportions (derived from frequencies only) of architectural elements in different subsets, classified according to climate type into semiarid, subhumid and humid basins.

All the data stored can be filtered according to the way case studies or individual subsets are classified on the basis of their external controls and depending variables. Provided that a statistically significant amount of data is gathered, it will be possible to exploit the database output to conduct **quantitative comparisons of the architecture of fluvial depositional systems in different contexts**; this will make it possible to gain insights into the effective role of the different controlling factors governing the sedimentary architecture of fluvial systems. Moreover, combining all the types of information herein presented, will enable the generation of **synthetic models of fluvial architecture** (cf. Baas et al., 2005), which are represented by distinctive stacking patterns and lithosome geometries, modes of internal organization and reciprocal relationships. Furthermore, it will be possible to generate information to be used as **input for numerical models of fluvial architecture**, such as distributions of dimensional parameters and transition probability matrices, that can be tailored to suit the particular characteristics of the depositional context. The utility of the database as an instrument for the **evaluation of the influence of sampling density** on observations and interpretations will also be tested.

CONCLUSIONS & FUTURE WORK

A relational database for the digitization of fluvial architecture has been devised, developed and populated with literature-derived case studies.

The early output tests demonstrate the potential impact of this tool on fluvial geology research, as an instrument than can be used mainly for:

a) improving our understanding of fluvial architecture in different settings and testing sensitivity to different controlling factors;

b) overcoming depositional and facies models, which are frequently based on few examples that are thought to be representative, but which may in fact be misleading;

c) assisting prediction of subsurface reservoir architecture through deterministic or stochastic models.

FUTURE DEVELOPMENTS The database will be further developed to make it better suitable for these purposes.

Several improvements can be put into practice, among them:

- better geometrical representation either through linkage to 2D/3D vector files of each lithosome object or inclusion of shape parameters;
- appending of particle-scale and/or diagenetic properties;
- refinement of subset attributes (e.g. addition of meta-attributes for time-scale specification).

Moreover, similarly to what has been done for ancient fluvial systems case histories, a standard data definition and entry procedure must be established for digitizing modern rivers examples.

Most of the future work will focus on database population, with more literature and field case studies, and on testing its capabilities, also through numerical modelling once enough data is stored.

References

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